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Puget Sound Estuary Program

ELLIOTT BAY ACTION PROGRAM:

Evaluation of Sediment Remedial Alternatives

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ELLIOTT BAY ACTION PROGRAM:
EVALUATION OF SEDIMENT REMEDIAL ALTERNATIVES

by

Tetra Tech, Inc.

for

U.S. Environmental Protection Agency
Region X - Office of Puget Sound
Seattle, Washington

April 1988

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PREFACE

This document was prepared by Tetra Tech, Inc. for the U.S. Environmental Protection Agency (EPA) Region X, Office of Puget Sound under the Elliott Bay Action Program work assignment of U.S. EPA Contract No. 68-02-4341. The primary objective of the Elliott Bay Action Program is to identify toxic contamination and appropriate corrective actions in Elliott Bay and the lower Duwamish River. Corrective actions include source controls and sediment remedial actions. An Interagency Work Group, comprising representatives from the U.S. EPA, Washington Department of Ecology, and other resource management agencies, provides technical oversight for all work conducted under this work assignment.

In this report, preferred alternatives for the remediation of contaminated sediments in two Elliott Bay problem areas are identified. Preferred alternatives are assembled and selected based on sediment characteristics, environmental factors, and on the criteria of effectiveness, implementability, and cost. The intent of this document is to provide guidance to federal, state, and local agencies in the remediation of toxic contamination in Elliott Bay.

The following reports are also associated with this work assignment:

- Analysis of toxic problem areas (PTI and Tetra Tech 1988)

- Evaluation of potential contaminant sources

- Development of a revised action plan

- Evaluation of the relationship between source control and mitigation of contaminated sediments (Tetra Tech 1988c)

- Development of a storm drain monitoring approach (Tetra Tech 1988b)

- Development of a receiving environment monitoring approach.

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ACKNOWLEDGMENTS

This document was prepared by Tetra Tech, Inc. under the direction of Dr. Jean M. Jacoby, for U.S. EPA in partial fulfillment of Contract No. 68-0204341. Dr. Jack Gakstatter and Ms. Clare Ryan served as U.S. EPA Project Officers, and Dr. Don Wilson served as the Tetra Tech Program Manager.

The primary authors of this report are Mr. John Virgin and Dr. Jean Jacoby of Tetra Tech. Ms. Sue Trevathan of Tetra Tech performed technical editing and supervised report production. The approach presented in this document is based on work conducted for the Commencement Bay Nearshore/Tideflats Feasibility Study by Tetra Tech for the Washington Department of Ecology and U.S. EPA. Mr. G. Patrick Romberg of Municipality of Metropolitan Seattle (Metro), Mr. Merv Coover of ReTech, and Mr. Douglas Hotchkiss of the Port of Seattle provided technical guidance on various aspects of this report. Evaluation of contaminant sources in the study areas was performed by Ms. Beth Schmoyer and Ms. Lynne Kilpatrick-Howard of Tetra Tech.

The Elliott Bay Action Program has benefited from the participation of an Interagency Work Group (IAWG) and a Citizen's Advisory Committee (CAC). Duties of the IAWG and CAC included 1) reviewing program documents, agency policies, and proposed actions (including selection of problem areas for further study); 2) providing data reports and other technical information to U.S. EPA; and 3) disseminating action program information to respective interest groups or constituencies. We thank the IAWG and CAC members for their past and continuing efforts. We are especially grateful to Ms. Joan Thomas, Mr. Gary Brugger, and Mr. Dan Cargill for co-chairing the IAWG, and to Mr. David Schneidler and Ms. Janet Anderson for co-chairing the CAC.

1.0 INTRODUCTION

1.1 OBJECTIVES

The objective of this document is to describe and evaluate remedial alternatives for two highly contaminated problem areas in Elliott Bay, Seattle, Washington. This document is also intended to support the development of guidelines for evaluating sediment remedial actions, as specified in Element S-7 of the sediment remedial program in the Puget Sound Water Quality Management Plan [Puget Sound Water Quality Authority (PSWQA) 1987].

The two problem areas addressed herein were selected by the IAWG on the basis of observed high chemical contaminant concentrations in sediments and associated adverse environmental effects. The areas were also chosen because ancillary offshore and source data from previous studies of those sites were available (summarized in PTI and Tetra Tech 1988; Tetra Tech, in preparation). One of the two areas selected by the IAWG was the offshore area in the vicinity of the Denny Way combined sewer overflow (CSO). In this report, this site will be referred to as the Denny Way problem area. The other site selected by the work group was along the north shore of Harbor Island and is referred to as the North Harbor Island problem area.

1.2 OVERVIEW OF STUDY

The assessment of sediment remedial alternatives is based on data collected and compiled in support of the Elliott Bay Action Program, including problem area identification (PTI and Tetra Tech 1988), source evaluation (Tetra Tech in preparation), and evaluation of the relationship between source control and recovery of contaminated sediments (Tetra Tech 1988c).

The approach used to select sediment remedial alternatives is described in Sections 3.0-5.0. This approach is based on that used in the Commencement Bay Feasibility Study (Tetra Tech 1988a), and modified when necessary, for use in Elliott Bay. A brief description of this approach is provided in Section 2.0.

Study area characteristics, problem chemicals, and sources of contaminants are provided for each problem area in Section 3.0. In addition, the relationship between source control and sediment accumulation of problem chemicals is summarized in Section 3.0. Potentially applicable technologies for the remediation of contaminated sediments in the Elliott Bay study area are discussed in Section 4.0. In Section 5.0, generic sediment remedial alternatives are assembled and the various process options appropriate to each generic alternative are described. Guidelines to identify candidate process options and alternatives appropriate to the Elliott Bay problem areas are provided in Section 6.0. In Section 7.0, the guidelines for determining appropriate sediment remedial alternatives are applied to the North Harbor Island and Denny Way CSO problem areas to identify preferred alternatives.

1.3. STUDY AREA

Elliott Bay is a small embayment (21 km^2) located on the eastern shore of Puget Sound approximately midway between Admiralty Inlet and the Tacoma Narrows (Figure 1). The inner bay receives fresh water from the Duwamish River and most of the stormwater runoff from about 67 km^2 of highly developed land in metropolitan Seattle. The nearshore areas of Elliott Bay have been altered substantially from their natural state by anthropogenic activities.

The Duwamish River is a salt-wedge estuary that is influenced by tidal action throughout the lower 16 km of the river (including all of the riverine habitat within the study area). The lower 10 km of the Duwamish River is a straightened navigational channel that flows through heavily industrialized areas of the city. Harbor Island divides the river into the East and West Waterways near the mouth (Figure 2). The Duwamish drainage

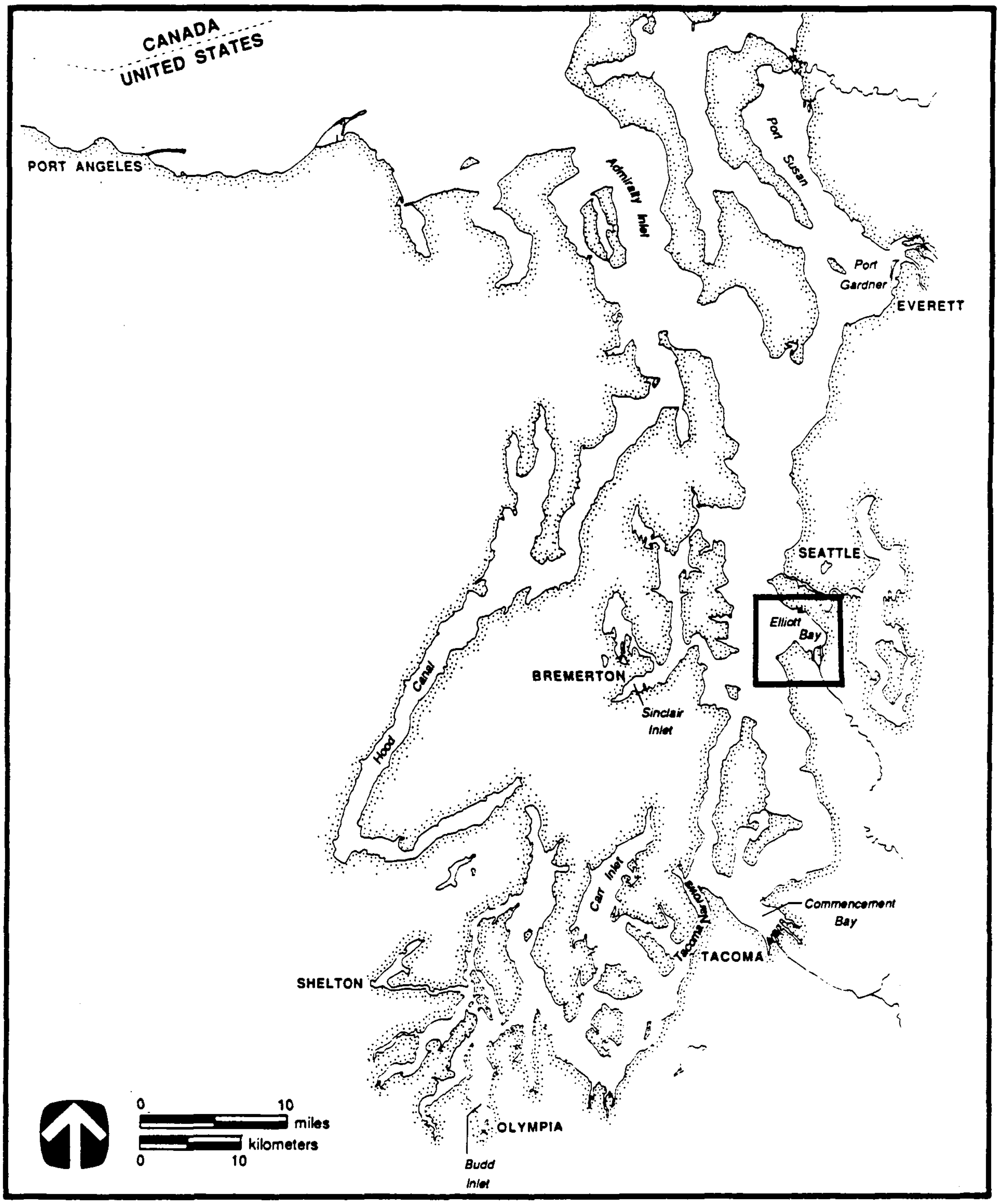

Figure 1. Project location: Elliott Bay and the lower Duwamish River.

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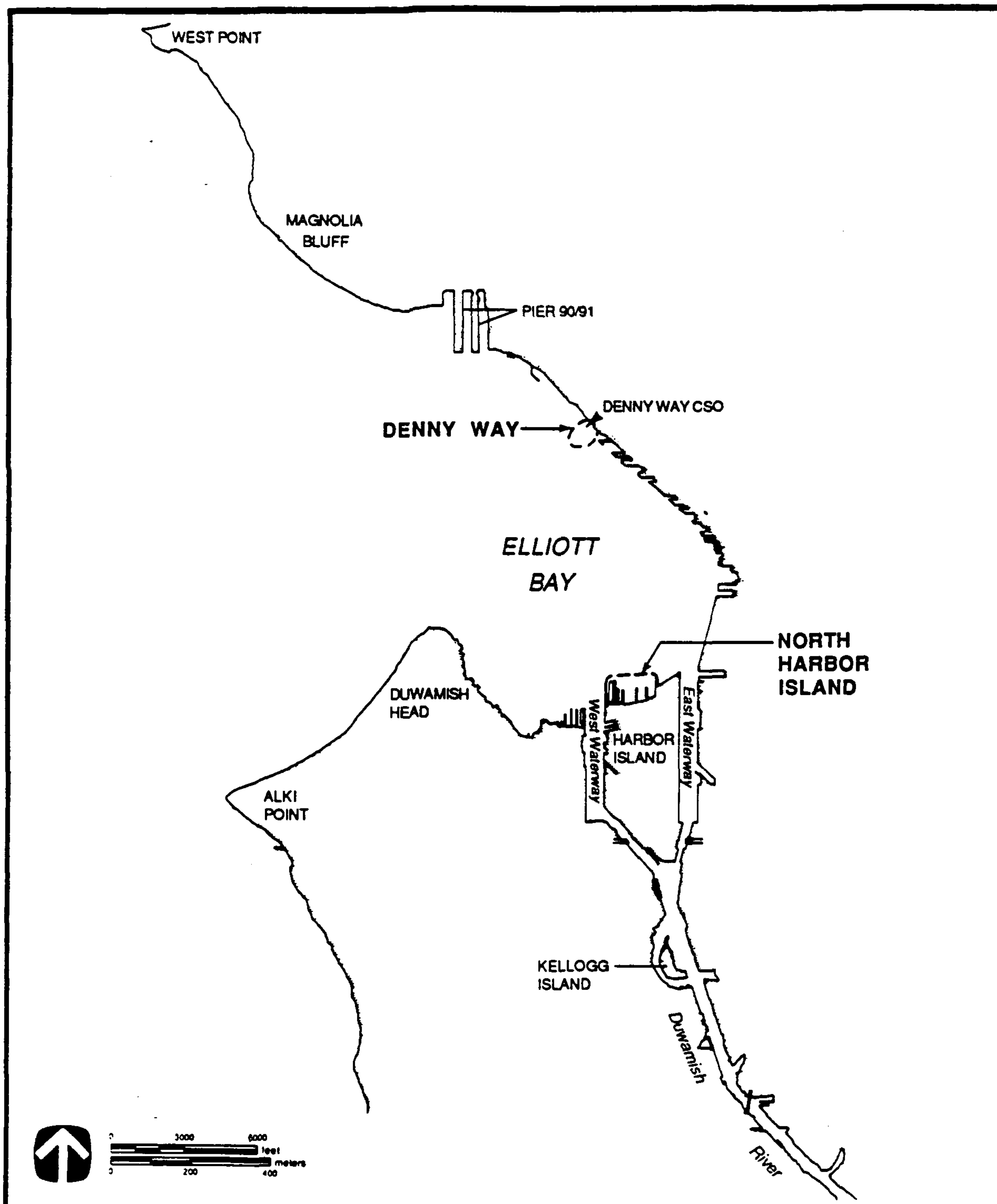

Figure 2. Approximate problem area boundaries used for selecting sediment remedial alternatives: Denny Way and North Harbor Island.

basin (1,250 km^2) includes large expanses of agricultural and forested lands in the upper basin.

The Denny Way and North Harbor Island sites (Figure 2) selected by the IAWG for assessment of sediment remedial alternatives are located within two of the high priority problem areas identified by PTI and Tetra Tech (1988). The Denny Way study site is located within the Seattle North Waterfront (NSI) problem area and the North Harbor Island study site is included within North Harbor Island-I (NHI) (Figure 3). These areas were identified as priority problem areas based on combined significant elevations of contaminant concentrations in sediments, fish pathology, and bioaccumulation (PTI and Tetra Tech 1988). The selected sites are described in greater detail in Section 3.0.

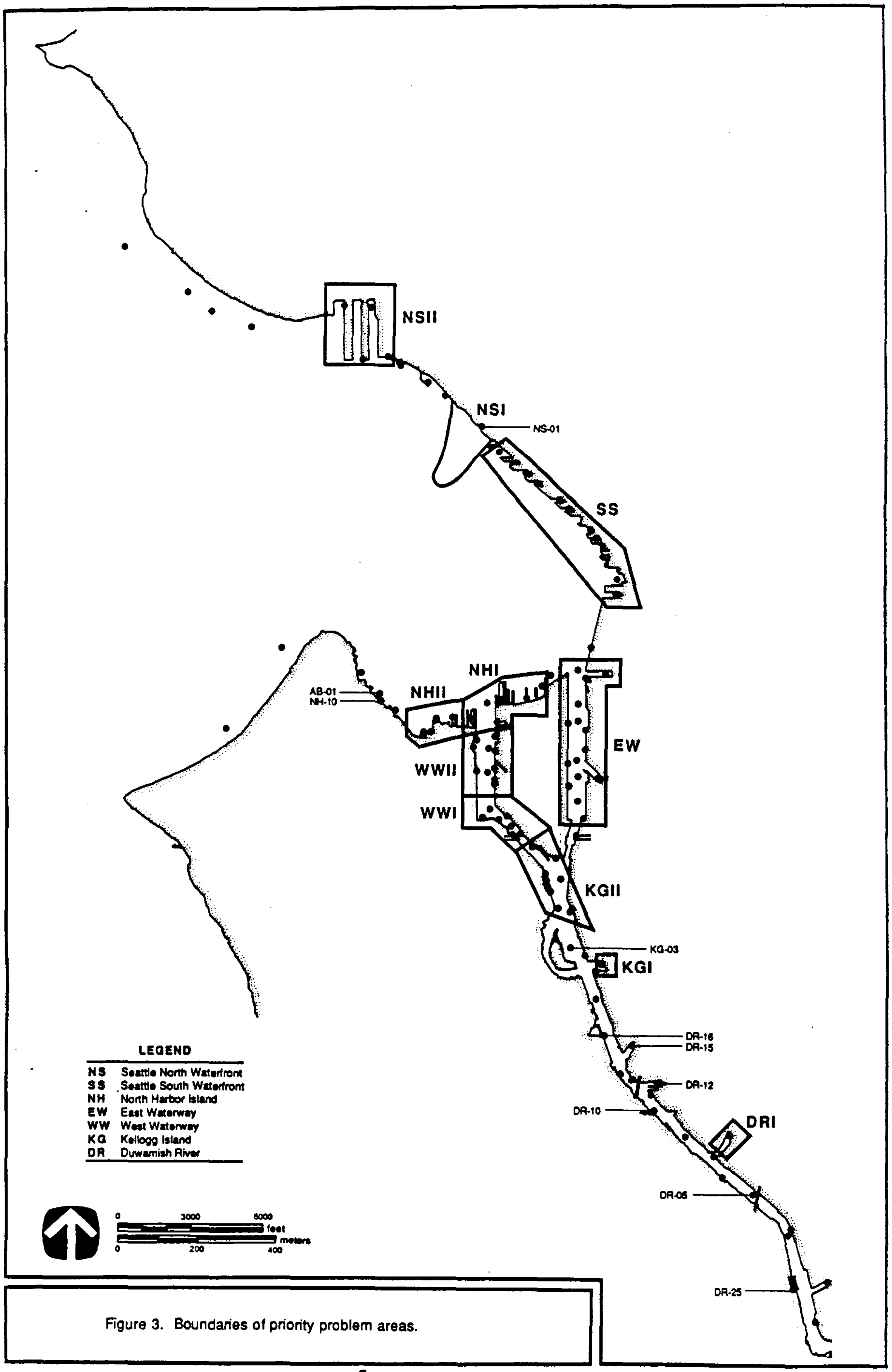

Figure 3. Boundaries of priority problem areas.

2.0 TECHNICAL APPROACH

The approach for assessment of remedial alternatives in Elliott Bay includes the following individual components (Tetra Tech 1988a):

- Identification of sediment cleanup goals (Tetra Tech 1986; Tetra Tech 1987b) picked lowest AET

- Identification and prioritization of problem areas and problem chemicals (PTI and Tetra Tech 1988)

- Evaluation of major sources (Tetra Tech in preparation)

- Development of an analytical approach 1) to establish the relationship between source loading and sediment accumulation of problem chemicals, and 2) to evaluate natural recovery of sediments following control of sources (Tetra Tech 1988c)

- Identification and screening of candidate sediment remedial alternatives

- Identification of preferred alternatives.

Each of the individual components is an integral part of the overall remediation effort. Development of sediment cleanup goals was performed during the Puget Sound Dredge Disposal Analysis Program (Tetra Tech 1986) and the Commencement Bay Feasibility Study (Tetra Tech 1987b). The following three components in the list were initiated under the Elliott Bay Action Program. Assessment of candidate sediment remedial alternatives is the focus of this document. The components of the technical approach for assessing remedial alternatives are discussed briefly in the following sections.

2.1 SEDIMENT CLEANUP GOALS

A working definition of acceptable chemical concentrations in sediments is required prior to evaluating sediment remedial alternatives. Because criteria for sediments are not yet available, sediment cleanup goals are based on the "apparent effects threshold" (AET) approach (Tetra Tech 1986). The focus of the AET approach is to identify concentrations of chemical contaminants in sediments that are associated with statistically significant biological effects (relative to reference conditions). Biological indicators used to develop AET values include:

- Depression in abundances of major taxonomic groups of benthic infauna (e.g., Crustacea, Mollusca, Polychaeta)
- Amphipod mortality bioassay using *Rhepoxynius abronius*
- Oyster larvae abnormality bioassay using *Crassostrea gigas*
- Microtox bioluminescence bioassay using *Photobacterium phosphoreum*.

For a given chemical and a specific biological indicator, the AET is the concentration above which statistically significant biological effects occurred in all samples of sediments analyzed.

AET values have been proposed for 64 organic and inorganic toxic chemicals using synoptic chemical and biological data from 200 stations in Puget Sound (Tetra Tech 1987b). For each chemical, a separate AET was developed for each biological indicator listed above, resulting in four sets of AET values. A list of the highest and lowest AET for each chemical is provided in Table 1. Sediment cleanup goals are based on the lowest AET value for problem chemicals.

not necessarily the
point where we take action
initiate ~~to~~ clean-up

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TABLE 1. PUGET SOUND AET VALUES
(ug/kg dry weight = ppb for organic compounds;
mg/kg dry weight = ppm for metals)

	Lowest AET[a]	Highest AET
LPAH[b]	5,200	6,100
Naphthalene	2,100	2,400
Acenaphthylene	560	640
Acenaphthene	500	980
Fluorene	540	1,800
Phenanthrene	1,500	5,400
Anthracene	960	1,900
HPAH[c]	12,000	38,000
Fluoranthene	1,700	9,800
Pyrene	2,600	11,000
Benzo(a)anthracene	1,300	4,500
Chrysene	1,400	6,700
Benzofluoranthenes	3,200	8,000
Benzo(a)pyrene	1,600	6,800
Indeno(1,2,3-c,d)pyrene	600	880
Dibenzo(a,h)anthracene	230	1,200
Benzo(g,h,i)perylene	670	5,400
Total PCBs	130	2,500
Total Chlorinated Benzenes	170	680
1,3-Dichlorobenzene	--	--
1,4-Dichlorobenzene	110	260
1,2-Dichlorobenzene	35	50
1,2,4-Trichlorobenzene	31	64
Hexachlorobenzene	70	230
Total Phthalates	3,300	3,400
Dimethyl phthalate	71	160
Diethyl phthalate	--	200
Di-n-butyl phthalate	1,400	1,400
Butyl benzyl phthalate	63	470
Bis(2-ethylhexyl) phthalate	1,900	1,900

TABLE 1. (Continued)

	Lowest AET[a]	Highest AET
Pesticides		
4,4'-DDE	9	15
4,4'-DDD	2	43
4,4'-DDT	3.9	11
Phenols		
Phenol	420	1,200
2-Methylphenol	63	63
4-Methylphenol	670	1,200
2,4-Dimethyl phenol	29	29
Pentachlorophenol	--	--
2-Methoxyphenol	930	930
Miscellaneous Extractables		
Hexachlorobutadiene	120	290
1-Methylphenanthrene	310	370
2-Methylnaphthalene	670	670
Biphenyl	260	270
Dibenzothiophene	240	250
Dibenzofuran	540	540
Benzyl alcohol	57	73
Benzoic acid	650	650
n-Nitrosodiphenylamine	40	220
Volatile Organic Compounds		
Tetrachloroethene	140	140
Ethyl benzene	33	37
Total xylenes	100	120
Metals		
Antimony	3.2	26
Arsenic	85	700
Cadmium	5.8	9.6
Copper	310	800
Lead	300	700
Mercury	0.41	2.1
Nickel	28	49
Silver	5.2	5.2
Zinc	260	1,600

Table 1. (Continued)

[a] By definition, the lowest AET is the sediment cleanup goal.

[b] LPAH = Low molecular weight polynuclear aromatic hydrocarbons.

[c] HPAH = High molecular weight polynuclear aromatic hydrocarbons.

Reference: Tetra Tech (1987b).

2.2 IDENTIFICATION OF PROBLEM AREAS AND PROBLEM CHEMICALS

The identification and subsequent ranking of problem areas and problem chemicals in Elliott Bay were performed under the Elliott Bay Action Program (PTI and Tetra Tech 1988). Synoptic sediment chemistry data, sediment toxicity, and benthic infauna data were used to characterize the environmental hazard of contaminated sediments in the nearshore region (i.e., less than about 50 m deep) of Elliott Bay and the lower Duwamish River. The magnitude and spatial distribution of sediment contamination in the North Harbor Island and Denny Way CSO problem areas in Elliott Bay are summarized in Section 3.0.

Problem chemicals were assigned priority based on the relative number of stations in each study area where concentrations exceeded the sediment cleanup goal. Chemistry data compiled from the following references were utilized to identify the problem chemicals in each of the study areas:

- Denny Way
  - Malins et al. 1980
  - Romberg et al. 1984
  - Romberg et al. 1987
  - PTI and Tetra Tech 1988
- North Harbor Island
  - Malins et al. 1980
  - U.S. EPA 1982; 1983
  - Romberg et al. 1984
  - Stober and Chew 1984
  - Gamponia et al. 1986
  - PTI and Tetra Tech 1988.

These data are presented in Appendices A and B.

For chemicals that were measured at multiple stations within a problem area, a high priority was assigned if the compound was detected at a concentration greater than the sediment cleanup level in at least 40 percent of the samples. A low priority was assigned to chemicals that were detected at a frequency of 40 percent or less. In addition, a low priority was assigned to contaminants which were analyzed for at only one station within a problem area.

Because of the difficulty in evaluating remedial alternatives for problem areas impacted by a wide variety of chemical compounds, a set of "indicator chemicals" was defined for the Denny Way and North Harbor Island problem areas. The indicator chemicals are a subset of each area's problem chemicals. Indicator chemicals were selected based on the following criteria:

- Frequency of sediment cleanup goal exceedance
- Spatial distribution of concentrations exceeding the cleanup goals
- Magnitude of cleanup goal exceedance
- Resistance to degradation.

The ratio of contaminant concentration in surface sediments to its respective cleanup goal (C_0/C_g) (the enrichment ratio) was used to evaluate the frequency, distribution, and magnitude of cleanup goal exceedance. A schematic of the process used to identify high priority, low priority, and indicator chemicals is presented in Figure 4.

2.3 EVALUATION OF MAJOR SOURCES

An evaluation of potential contaminant sources in Elliott Bay is currently being conducted as a component of the Elliott Bay Action Program (Tetra Tech in preparation). Without source control, sediment quality in

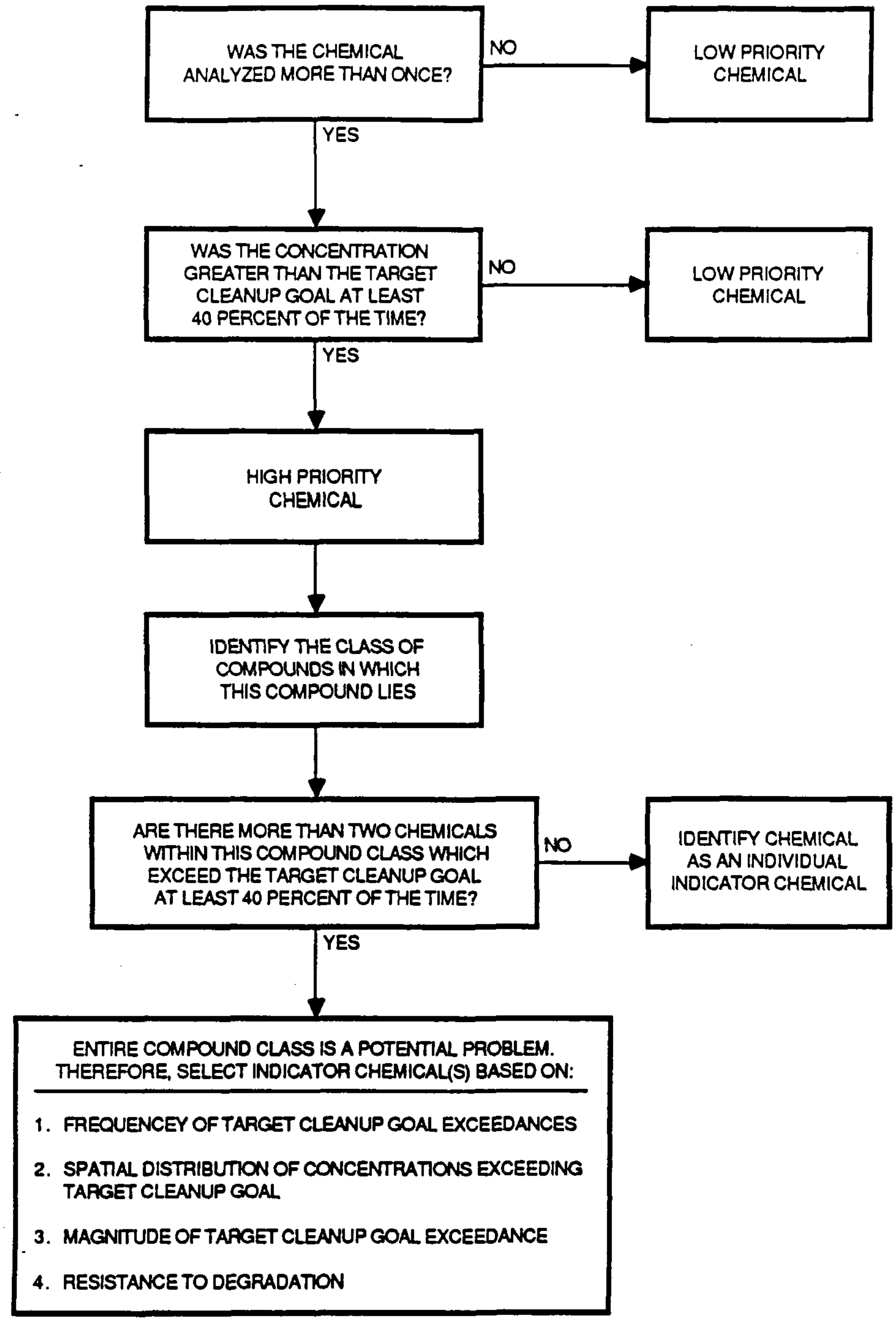

Figure 4. Flow chart for the identification of indicator chemicals.

newly remediated problem areas would degrade in response to inputs of contaminated sediments.

Potential sources, such as CSOs and storm drains, are being identified and ranked based on chemical contaminant concentrations measured in sediments collected from the drains (Tetra Tech in preparation). The source evaluation focuses on the high priority problem areas identified in the receiving environment (PTI and Tetra Tech 1988). Relationships between potential sources and problem areas are being evaluated using available source and offshore sediment chemistry data, and ancillary information on drainage basin characteristics, industrial activities, and historical sources. The status of contaminant sources in the Denny Way CSO and North Harbor Island problem areas is summarized in Sections 3.1.3 and 3.2.3.

2.4 RESPONSE OF SEDIMENTS TO SOURCE CONTROL

The evaluation of the relationship between source control and sediment accumulation of contaminants is essential to the development of sediment recovery scenarios and the identification of appropriate sediment remedial alternatives. Following source control, the deposition of clean sediment will tend to mitigate chemical contamination and associated adverse environmental effects in surface sediments.

An analytical approach was developed to evaluate the relationship between source control and sediment recovery in the Commencement Bay Feasibility Study (Tetra Tech 1987a). In that study, sediment recovery in contaminated problem areas was predicted through the application of the Sediment Contamination Assessment Model (SEDCAM). SEDCAM is a mass balance equation that attempts to predict the sediment concentration of contaminants in relation to source loading, sedimentation rates, mixing, biodegradation, and loss across the sediment-water interface. To apply this approach, it was necessary to estimate the degree of source control that is feasible for individual problem areas.

The model was also applied to the two problem areas in Elliott Bay to assess the potential success of source control (Tetra Tech 1988c). Results from the application of the model to the Denny Way CSO and North Harbor Island problem areas were used in this study to determine the necessity of additional corrective actions such as sediment remediation (see Sections 3.1.4 and 3.2.4).

2.5 SEDIMENT REMEDIAL ALTERNATIVES

Sediment remedial alternatives were developed through the following steps (Tetra Tech 1988a):

- Develop a thorough list of available remedial technologies for the isolation, removal, treatment, and/or disposal of contaminated sediments

- Conduct an initial screening of available remedial technologies to identify candidate technologies that may be appropriate for the study area

- Develop specific combinations of appropriate technologies to define a wide range of complete sediment remedial alternatives

- Screen the candidate sediment remedial alternatives to develop a discrete and concise set of alternatives appropriate for the individual problem area.

Through this process, different sediment remedial alternatives were developed that can be applied on an area-wide basis to the Elliott Bay problem areas.

Remedial technologies and corresponding process options were identified within seven response action categories: no action, institutional controls, in situ containment, removal, in situ treatment, post-removal treatment, and disposal. Through an initial screening process, technologies and process options were eliminated as not being appropriate at this time for the Elliott Bay problem areas. The sediment remedial technologies and process options that passed the initial screening were combined to form area-wide alternatives:

- No action
- Institutional controls
- In situ containment
- Removal and disposal
- Removal, treatment, and disposal.

The area-wide alternatives were then screened to develop a specific set of alternatives for each problem area.

Implementation of preferred sediment remedial alternatives must be coordinated with source controls, if acceptable sediment quality is to be maintained. Institutional requirements, source control measures, and sediment remedial actions will be incorporated in the Elliott Bay Revised Action Plan (PTI and Tetra Tech in preparation) to identify, prioritize, and integrate remedial activities. The overall objective of this plan is to outline actions by individual agencies and cooperative efforts among the agencies to correct identified problems in Elliott Bay.

2.6 SELECTION OF PREFERRED ALTERNATIVES

A detailed analysis of sediment remedial alternatives and selection of preferred alternatives is the final stage of the evaluation process (Tetra Tech 1988a). Evaluation criteria for the detailed analysis can be grouped into three general categories: effectiveness, implementability, and cost. Four effectiveness criteria were used: short-term protectiveness; timeliness; long-term effectiveness; and reduction in contaminant toxicity, mobility, or volume. Three implementability criteria have been included: technical feasibility, institutional feasibility, and availability of disposal facilities. Cost criteria were divided into: 1) initial costs, including design and specification preparation and capital construction; and 2) operation and maintenance (O&M) costs, including monitoring. A present value analysis was used for cost comparisons using the lowest AET cleanup goals to define the area requiring remediation.

A matrix comparison process was used to support the evaluation of alternatives for each problem area. First, a narrative matrix was prepared to provide a complete analysis of all criteria. Second, an evaluation summary matrix was prepared using a reduced set of criteria. Each alternative was rated as either low, moderate, or high with respect to meeting each of the summary criteria. A preferred alternative was then selected for sediment remediation in each problem area.

3.0 DESCRIPTION OF PROBLEM AREAS

3.1 DENNY WAY

3.1.1 Site Description

The Denny Way problem area is located north of the downtown Seattle area offshore of the Denny Way CSO outfall (Figure 2). This area is characterized by high concentrations [i.e., exceeding high AET values (HAET) (Table 1)] of mercury, silver, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs), and several chlorinated pesticides (PTI and Tetra Tech 1988).

Although contaminant loading from the Denny Way CSO has been decreasing in recent years, this CSO has been identified as a major contributor of chemical contaminants to bottom sediments near the site (Romberg et al. 1987). Elevated concentrations of organic compounds and heavy metals are present in bottom sediments near the outfall (Tomlinson et al. 1980; Malins et al. 1980; Romberg et al. 1984; Romberg et al. 1987). In addition, altered benthic communities have been observed concomitant with elevated chemical concentrations in the vicinity of the outfall (Armstrong et al. 1978; Cominskey et al. 1984; Chapman et al. 1982). Recent source control efforts by Metro have reduced toxicant loading to the CSO (Romberg et al. 1987). However, sediment remedial actions may be required to improve environmental conditions in offshore sediments.

3.1.2 Indicator Chemicals

Mercury, fluoranthene, chrysene, butyl benzyl phthalate, bis(2-ethylhexyl)phthalate, and total PCBs were selected as indicator chemicals for the development of sediment recovery scenarios and evaluation of sediment remedial alternatives. Table 2 identifies all of the compounds determined to have an enrichment ratio [i.e., ratio of contaminant concentration in

TABLE 2. IDENTIFICATION OF INDICATOR CHEMICALS IN DENNY WAY CSO OFFSHORE SEDIMENTS

Compound	Largest Enrichment Ratio	Number of Historical Analyses with Ratio >1	Number of PTI and Tetra Tech (1988) Analyses with Ratio >1	Total No. of Analyses with Ratio >1	Number of Samples Analyzed	Percent of Samples with Ratio >1
METALS						
Cadmium	1.1	2	0	2	35	6
Lead	1.8	6	0	6	42	14
Silver	1.6	1	1	2	7	29
Zinc	2.1	14	0	14	42	33
Mercury	6.4	32	1	33	36	92
LPAH						
Phenanthrene	66	8	0	8	24	33
Anthracene	42	6	0	6	25	24
Fluorene	58	4	0	4	21	19
Acenaphthene	26	1	0	1	21	5
Total LPAH	36	3	0	3	21	14
HPAH						
Fluoranthene	36	10	0	10	25	40
Pyrene	14	6	0	6	25	24
Benzo(a)anthracene	8.2	8	0	8	23	35
Chrysene	19	10	0	10	23	43
Benzo(a)pyrene	4.7	6	0	6	23	26
Indeno(1,2,3-cd)pyrene	2.2	8	0	8	23	35
Benzo(g,h,i)perylene	2.1	7	0	7	22	32
Benzo(b+k)floranthene	5.1	4	0	4	21	19
Total HPAH	13	7	0	7	21	33
Phthalates						
Butylbenzylphthalate	29	17	0	17	21	81
di-n-butyl phthalate	1.2	2	0	2	22	9
Dimethylphthalate	2.5	1	0	1	22	5
Bis (2-ethylhexyl) phthalate	28	13	0	13	20	65
Total phthalates	17	13	0	13	21	62

Table 2. (Continued)

Pesticides/PCBs						
4,4'-DDE	2	1	0	1	2	50
4,4'-DDD	6	1	DL > AET[a]	1	2	50
4,4'-DDT	24	1	DL > AET	1	2	50
Total PCBs	20	27	DL > AET	27	33	82
Phenols						
Phenol	4.5	4	0	4	21	19
Pentachlorophenol	5.6	2	0	2	21	10

[a] Method detection limit exceeded cleanup goal.

surface sediments relative to its respective cleanup goal (C_0/C_g)] greater than 1 for at least one of the 42 stations. Locations of the 41 (including 1 duplicate station) sampling stations are presented in Figure 5. Areal distributions of the indicator chemicals are presented in Figures 6-11. Appendix A summarizes the data evaluated to identify the indicator chemicals in the Denny Way problem area.

3.1.3 Source Summary

The Denny Way CSO has a shoreline discharge at the north end of Seattle (Figure 2) and is the largest CSO discharging untreated wastewater into Elliott Bay. It discharges a total average volume of 500 million gal/yr from approximately 30 to 60 times in a given year when trunk lines leading to the municipal wastewater treatment plant overflow. These are referred to as overflow events. The service area consists of approximately 1,900 ac of mixed residential and commercial land.

Metro's Toxicant Pretreatment Planning Study (TPPS) (Cooley et al. 1984) is the primary source of information on the chemical composition of CSO discharges to Elliott Bay. In addition to the TPPS data, the Denny Way CSO has been sampled as part of other Metro CSO studies (Tomlinson et al. 1976; 1980). Comparisons between available water quality criteria and concentrations of chemical contaminants in the CSO discharge samples indicated exceedance of criteria for metals such as copper, silver, and zinc. Characterization of contaminant loading in CSO discharge samples has been hampered by natural variations in environmental conditions and by the relatively limited number of samples collected.

In 1986, Metro conducted a trial study in the Denny Way CSO drainage basin to determine if toxicant sources could be identified and reduced (Romberg et al. 1987). As part of the investigation, Metro developed an inventory of 530 potential sources in the drainage basin based on Standard Industrial Codes (SIC) and addresses from tax records. A questionnaire on wastewater discharges and chemical use was sent to those businesses identified as potential sources. Fifty-four percent of the businesses contacted responded to the questionnaire. Those businesses that failed to

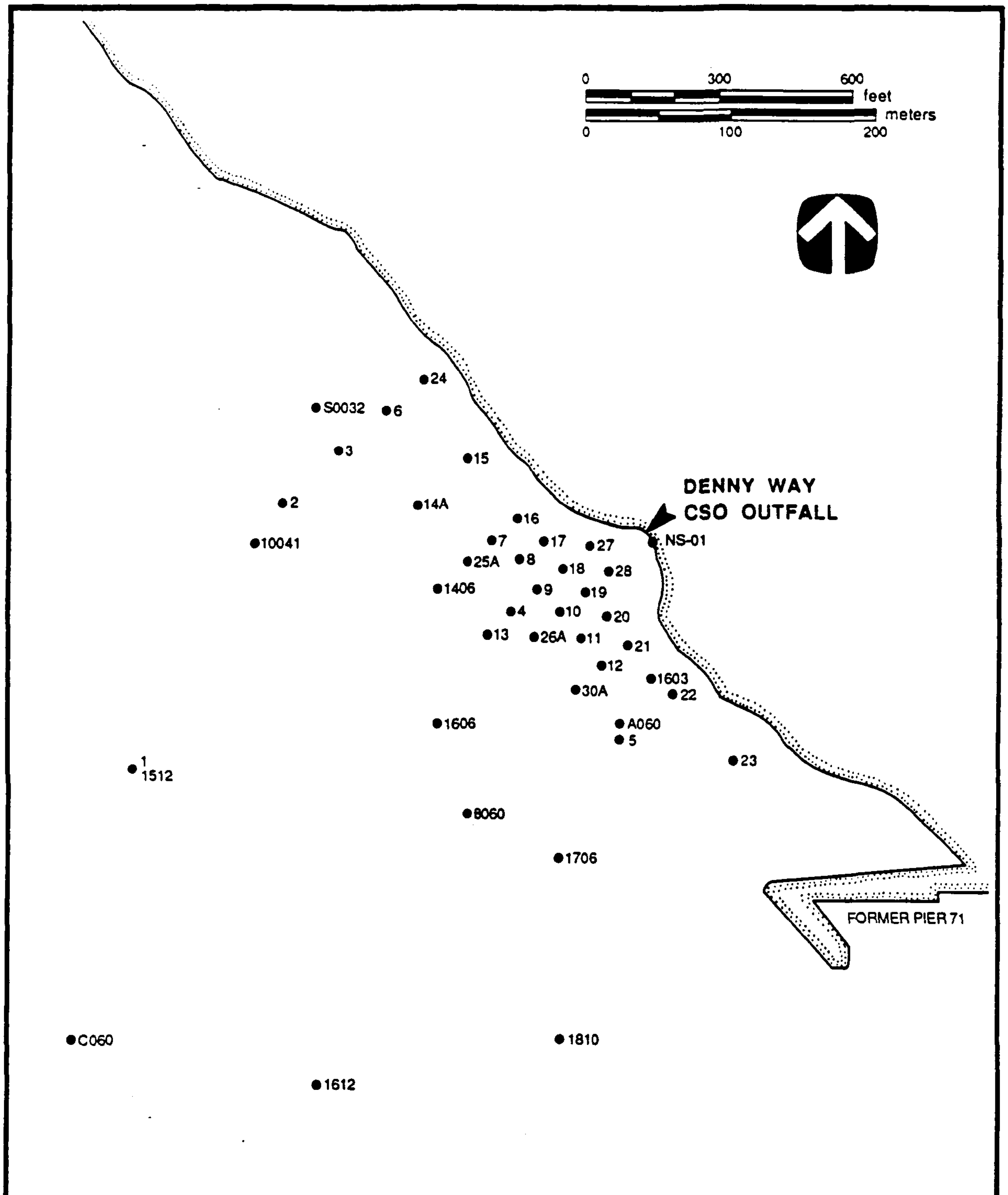

Figure 5. Sampling station locations in the Denny Way problem area.

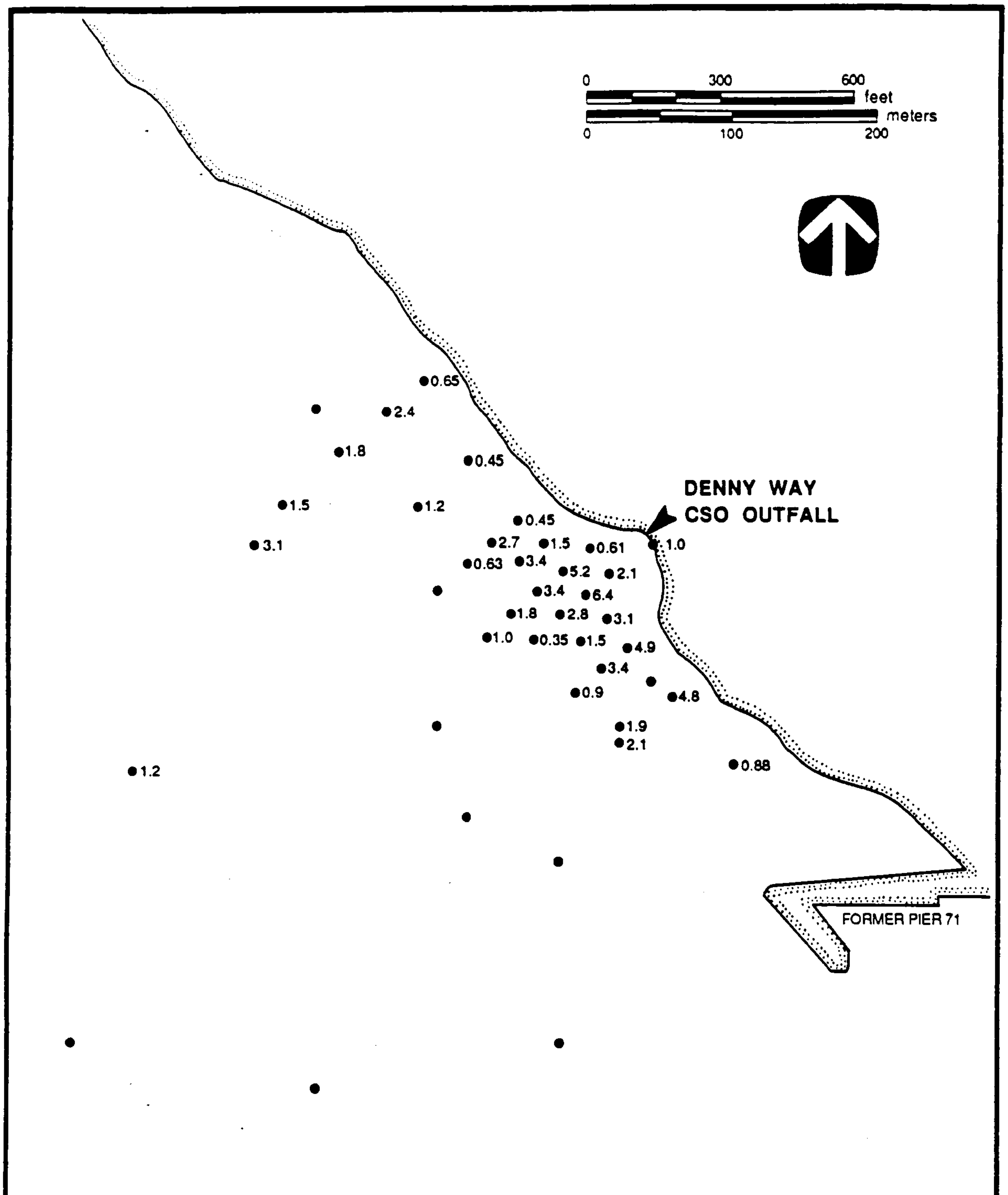

Figure 6. Areal distribution of mercury concentrations in Denny Way surficial sediments, corrected for background concentration and normalized to the target cleanup goal (C_O/C_G).

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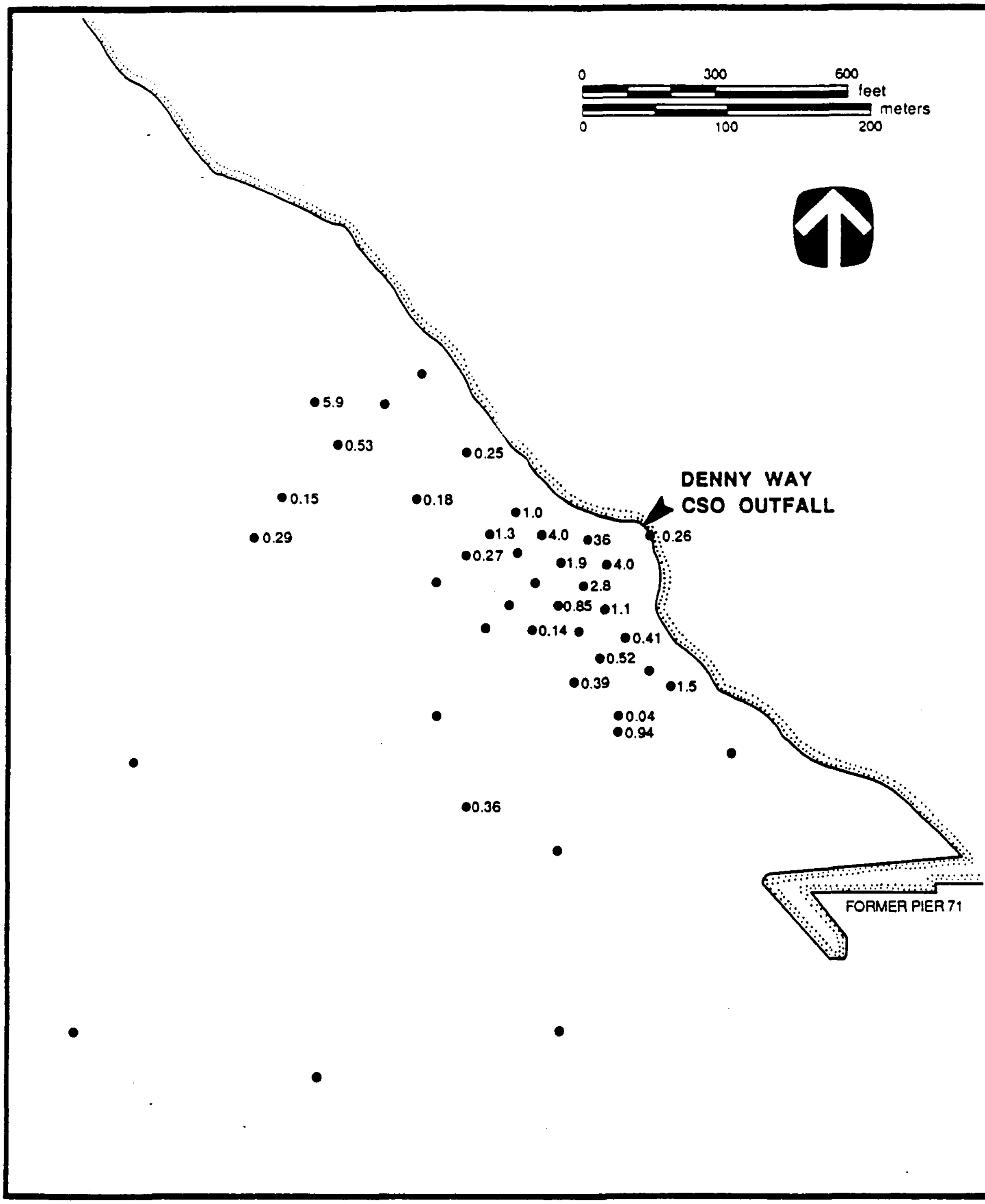

Figure 7. Areal distribution of fluoranthene concentrations in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

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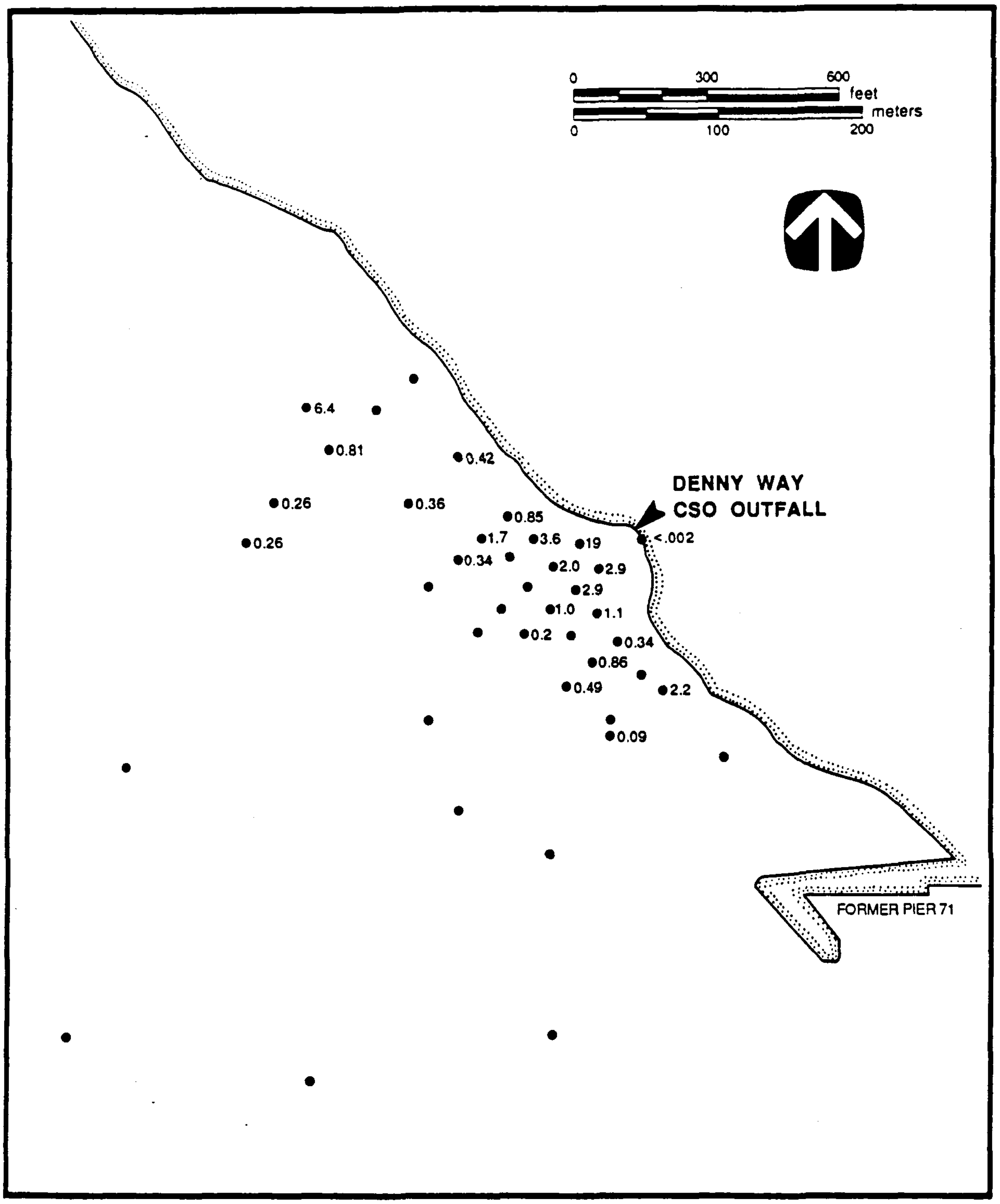

Figure 8. Areal distribution of chrysene concentrations in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

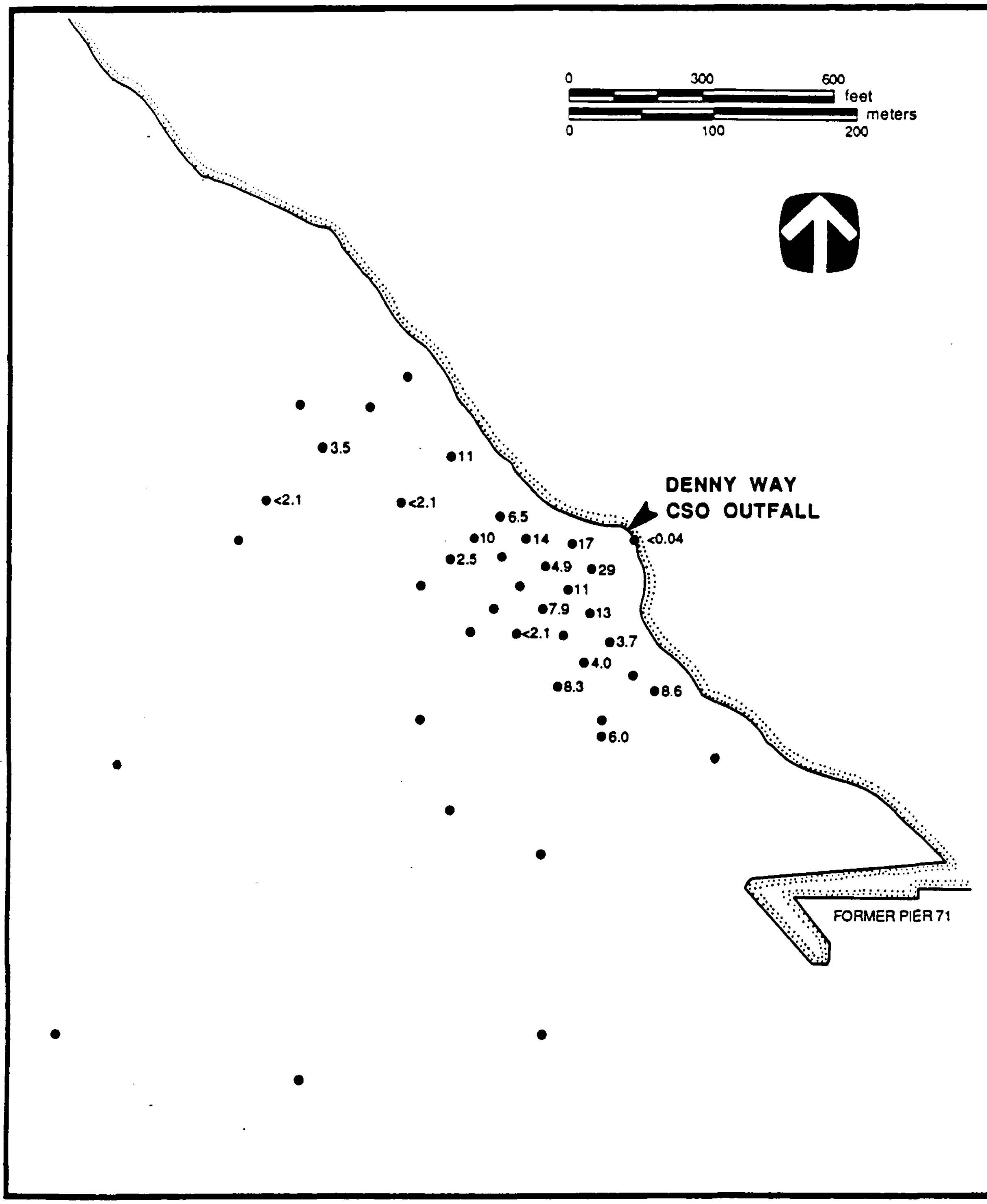

Figure 9. Areal distribution of butyl benzyl phthalate concentrations in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

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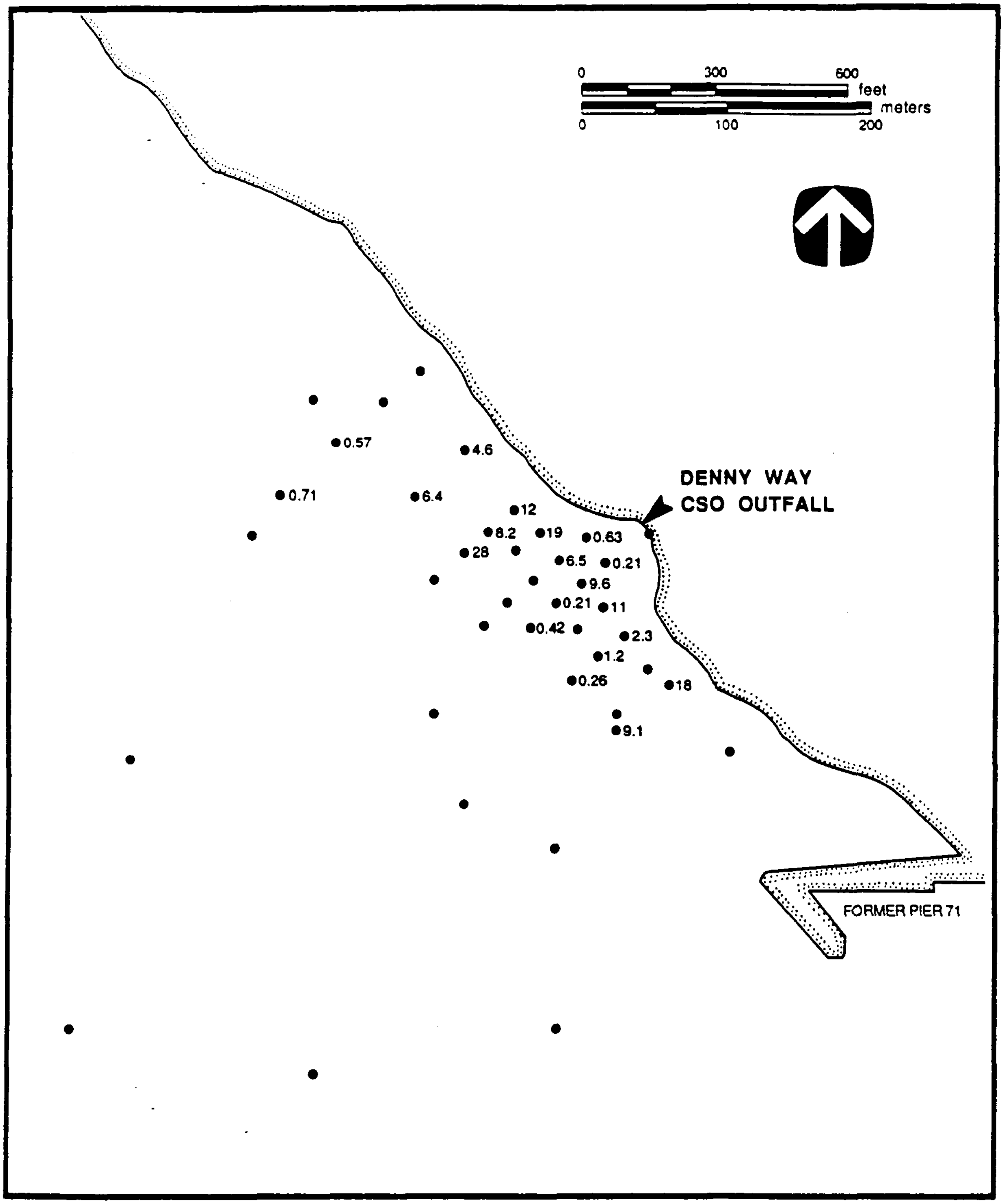

Figure 10. Areal distribution of bis(2-ethylhexyl)phthalate concentrations in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

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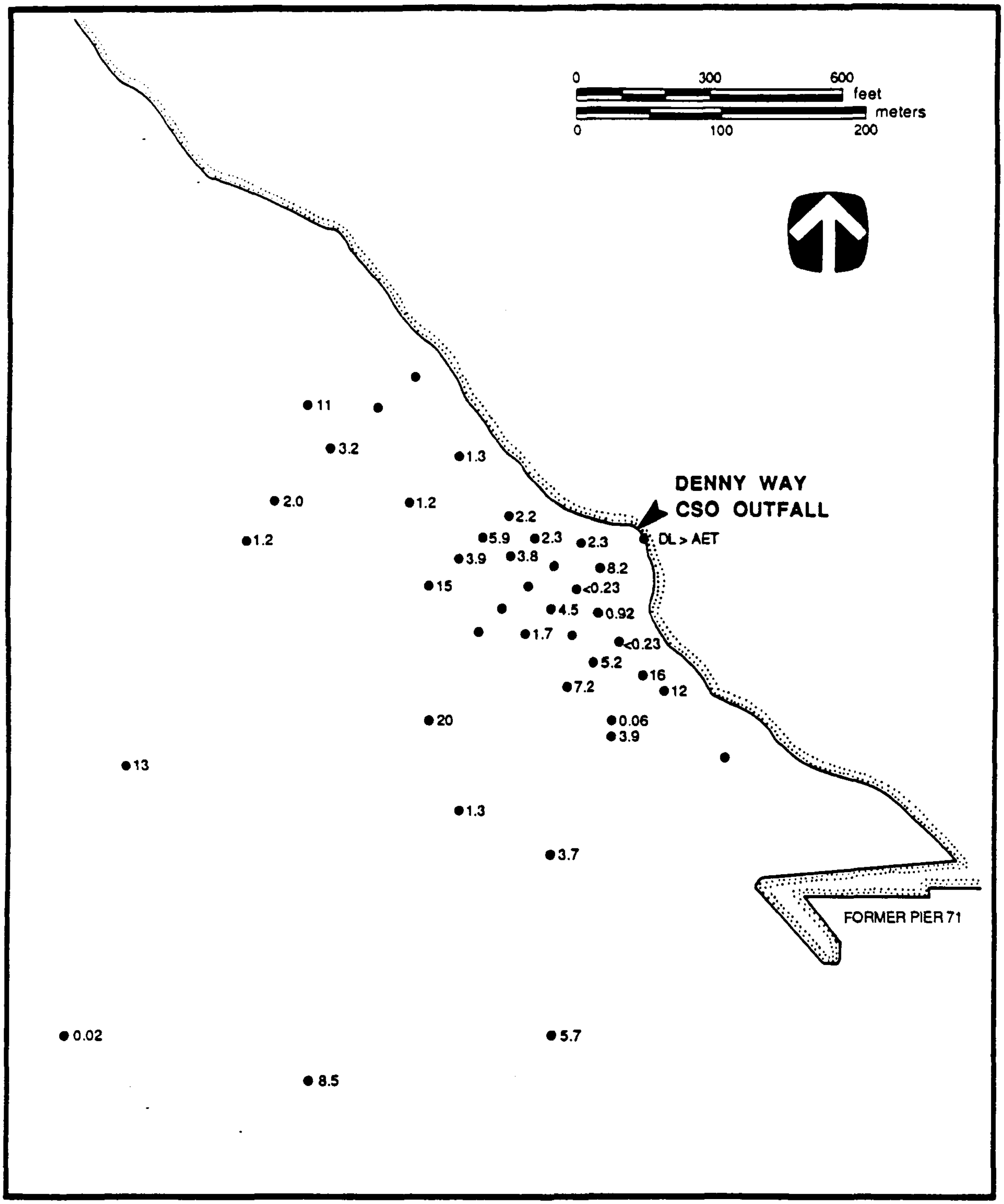

Figure 11. Areal distribution of total PCB concentrations in Denny Way surficial sediments, normalized to the target cleanup goal (C_O/C_G).

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respond were visited or contacted by phone. Ninety-six potential sources were selected based on the results of the questionnaire survey. These sources were visited by Metro inspectors to confirm the questionnaire survey responses and to collect information to help develop practical source control strategies. In addition, sediment and wastewater samples were collected at key points within the CSO system (Figure 12) and analyzed for metals and organic toxicants. Wastewater samples were collected for two different events at most stations and sediment samples were collected once at each station (Romberg et al. 1987).

The highest metals concentrations in both wastewater and sediment samples were measured in stations downstream of two industrial laundries that discharge wastewater to the Denny Way CSO. In addition, a large volume of accumulated sediments in one part of the CSO system (Lake Union Tunnel), located downstream of both laundries, was found to have high metals concentrations. Both laundries installed new pretreatment equipment in 1986 to reduce the toxicant loadings in their discharges. Based on preliminary data, metals loadings in sediments and wastewater were estimated to have been reduced by 50 percent for copper, 77 percent for lead, and 24 percent for zinc after the pretreatment systems were installed (Romberg et al. 1987).

High concentrations of chromium and mercury in in-line discharge samples were traced to a movie film developing facility. The facility has been directed to use proper disposal practices, and as a result, the toxicant input from this source is expected to be eliminated or greatly reduced (Romberg et al. 1987).

Analyses of organic compounds were generally not as effective in tracing contaminant sources as with the analyses of metals because of large variations in organic compound concentrations among different sampling events at one station. However, concentrations of toluene, tetrachloroethane, and ethyl benzene were typically highest in the wastewater samples collected downstream of the two industrial laundries (Romberg et al. 1987). These three volatile organic compounds were also present at relatively high concentrations in sediment samples collected immediately downstream of the

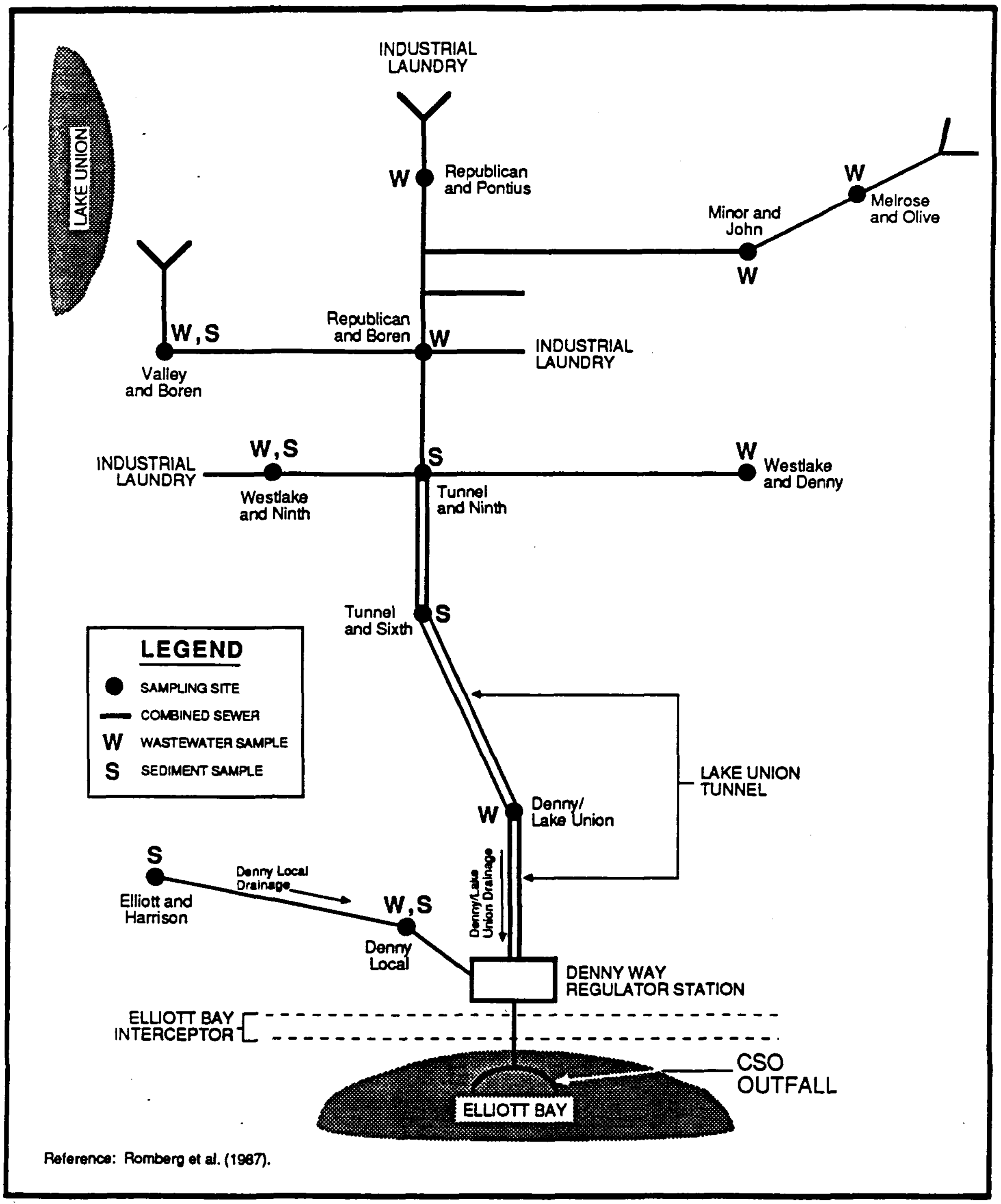

Figure 12. Sampling station locations in Metro's Denny Way CSO source toxicant investigation.

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laundries. In addition, naphthalene appeared to be associated with the industrial laundries, because it was only present (8.5-170 ug/L) in wastewater samples collected downstream of these two industrial laundries.

Metro is currently evaluating removal of the contaminated sediments in the Lake Union Tunnel to prevent them from being flushed into Elliott Bay. In addition, improvements in the stormwater routing program to enhance in-line storage, and a notification and control system to reduce source toxicant discharges when overflows occur are under consideration (Romberg et al. 1987). Projected stormwater separation measures are anticipated to reduce the number of CSO events from 50 events/yr to approximately 10 events/yr by the mid-1990s (Romberg and Sumeri 1988).

3.1.4 Source Control and Sediment Recovery

The relationship between source control and accumulation of chemical contaminants in Denny Way problem area sediments was evaluated through application of SEDCAM. The model and the results for the Denny Way problem area are reported in full in Tetra Tech (1988c). A summary of those results is presented below.

Key variables in understanding the sediment accumulation process include:

- Concentration of problem chemicals in recently deposited material
- Concentration of problem chemicals in surface sediments
- Sedimentation rate
- Depth of the mixed layer
- Rate at which problem chemicals are lost due to biodegradation and diffusion across the sediment-water interface.

The depositional parameters in the Denny Way problem areas were estimated based on studies performed by Romberg et al. (1987) in the vicinity of the outfall and by Carpenter et al. (1985) in shallow central Puget Sound bays. Two sedimentation rates (0.2 and 0.7 cm/yr) were selected for the model to provide a range in sediment recovery scenarios in this area (Tetra Tech 1988c). The lower rate is conservative and results in the longest sediment recovery time estimates. A mixing depth of 10 cm was selected for the model based on sediment profiles from cores collected in Commencement Bay (Tetra Tech 1987a) and other central Puget Sound shallow bays (Carpenter et al. 1985). Losses due to biodegradation and diffusion were determined to be negligible. The model was applied for the indicator chemicals noted in Section 3.1.2.

Results of the model application to the Denny Way problem area are presented in Figure 13 and are summarized below:

- At a sedimentation rate of 0.2 cm/yr, acceptable sediment concentrations (i.e., below cleanup goals) of the indicator chemicals will not be achieved before 90 yr after all contaminant loading has been eliminated

- Acceptable surface sediment concentrations are predicted to be achieved within 55 yr at a sedimentation rate of 0.7 cm/yr.

Thus, regardless of the sedimentation rate, elimination of sources of contaminants alone is not expected to result in sediment recovery in the Denny Way problem area within a reasonable timeframe because of the current level of contamination.

3.2 NORTH HARBOR ISLAND

3.2.1 Site Description

Harbor Island is located approximately 1 mi southwest of downtown Seattle, WA, where the Duwamish River flows into Elliott Bay (Figure 2). Harbor Island is a 405-ac island that was constructed during the early 1900s

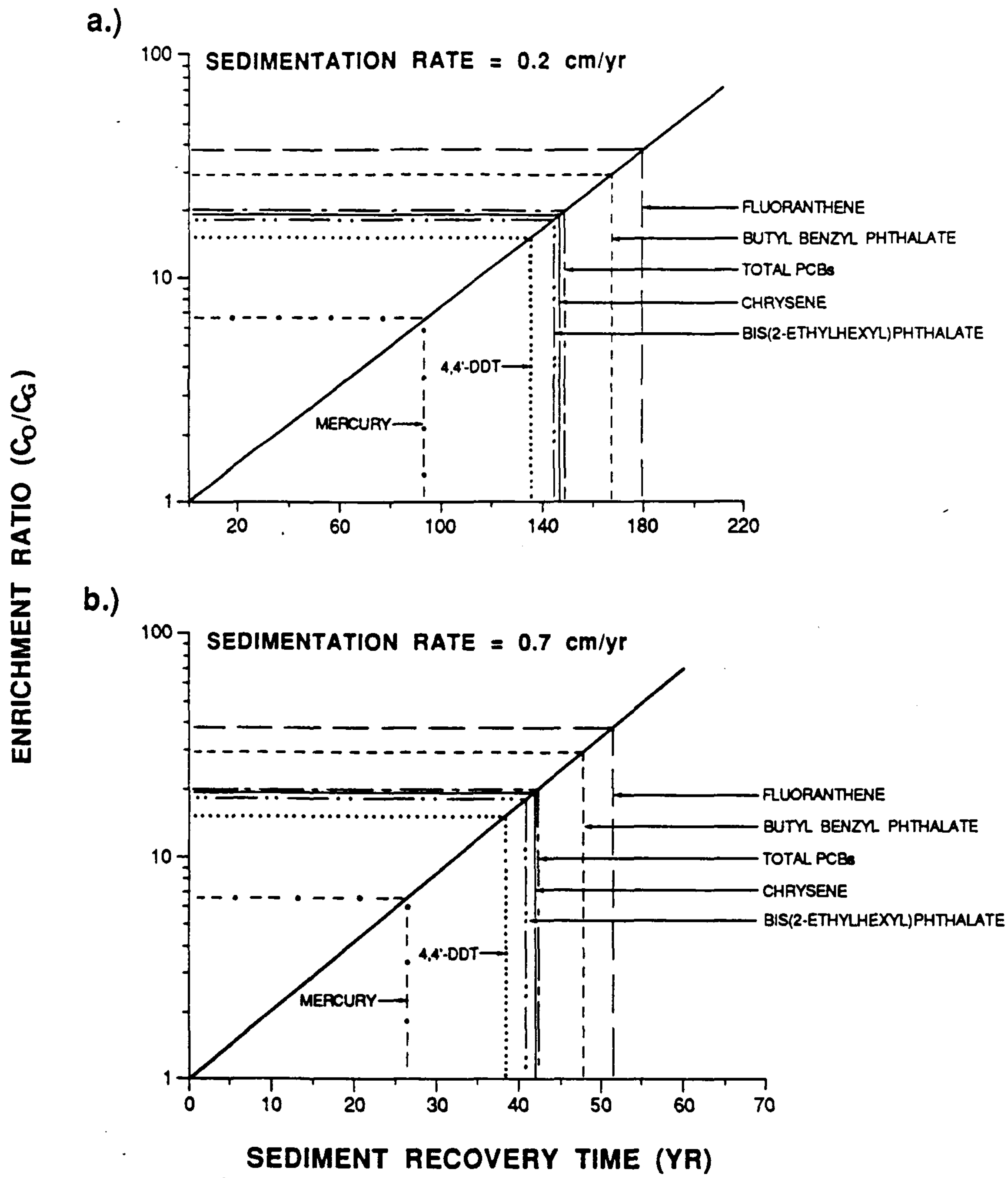

Figure 13. Sediment recovery model results for the Denny Way problem area: enrichment ratio based on maximum concentration vs. sediment recovery given 100 percent source control for sedimentation rates of 0.2 cm/yr (a) and 0.7 cm/yr (b).

in an area consisting of intertidal wetlands at the mouth of the Duwamish River. The island was created using sediments dredged to facilitate navigation in the lower Duwamish River and the West Waterway. Subsequently, debris from demolition and regrading projects in the Seattle area were used to complete construction of the island. Since construction, the island has been used for commercial and industrial activities. The commercial activities involve product storage and port and rail transport. Heavy industrial activities include secondary lead smelting, shipbuilding, and secondary metal processing.

The Harbor Island site was listed in the Superfund National Priorities List in 1980. There are two major environmental issues of concern for the site: 1) lead contamination from the previous operation of a secondary lead smelting facility on Harbor Island, and 2) releases of hazardous substances from other potential sources on the island. Background information pertaining to Harbor Island and the results of previous sampling efforts can be found in Black & Veatch (1985).

The North Harbor Island study area selected for evaluation of sediment remedial alternatives is located along the island's northern waterfront areas (Figure 2). This area is characterized by high concentrations of PAH, PCBs, and several metals (including copper, mercury, lead, zinc, and arsenic) (PTI and Tetra Tech 1988).

The following companies are located along the Harbor Island waterfront adjacent to the study area (Figure 14):

- Port of Seattle
    - Knappton Maritime Corporation
- Todd Shipyards Corporation
- Mobil Oil Corporation

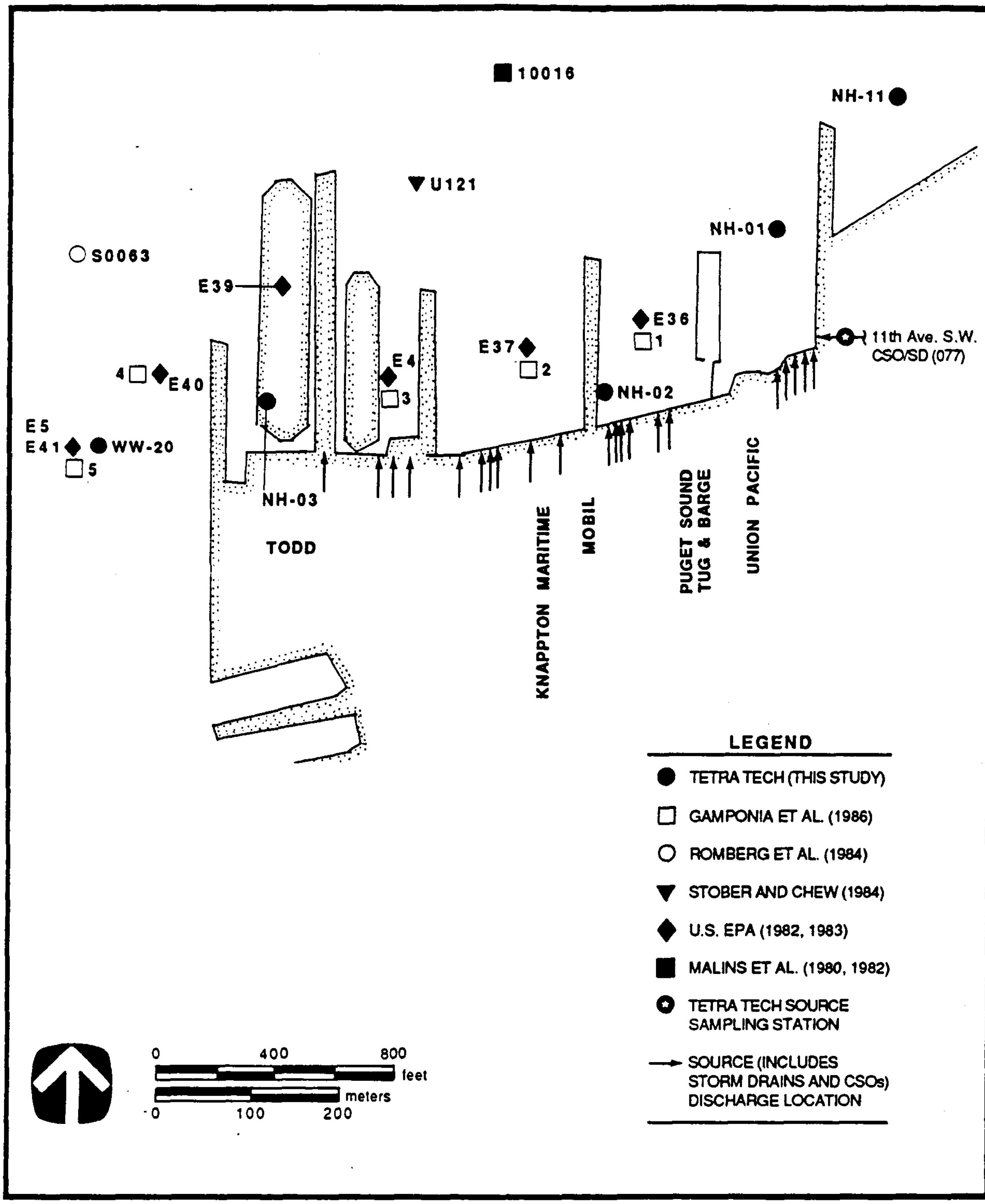

Figure 14. Locations of offshore sampling stations, potential sources, and industrial facilities along the North Harbor Island waterfront.

- Puget Sound Tug and Barge (subsidiary of Crowley Maritime Company)

- Union Pacific.

3.2.2 Indicator Chemicals

Mercury and total PCBs were selected as indicator chemicals for the development of sediment recovery scenarios and definition of the areal extent of contaminated sediments exceeding target cleanup goals at the North Harbor Island problem area. All compounds determined to have an enrichment ratio greater than 1 in one or more of the 20 samples collected in the problem area are shown in Table 3. Locations of the sampling stations are presented in Figure 15. Areal distributions of the indicator chemicals are presented in Figures 16 and 17.

Additional chemicals which met the criteria for indicator chemicals (Section 2.4.1) included zinc, pyrene, and 2,4-dimethylphenol. These chemicals were not included when defining the areal extent of contaminated sediments because they are included within the area defined by mercury and total PCBs. The largest enrichment ratios of any chemical measured in the North Harbor Island problem area was 60 for 4,4'-DDD (Table 3). This ratio was included in the development of sediment recovery scenarios (Section 3.2.4). Appendix B summarizes the data evaluated to identify the indicator chemicals in the North Harbor Island problem area.

3.2.3 Source Summary

Harbor Island is served by a combination of city and private storm drain systems. The city system serves approximately 280 ac located primarily on the interior of the island (Tetra Tech 1988d). The exterior part of the island (approximately 120 ac) immediately adjacent to the waterways and Elliott Bay is serviced by private storm drains that have been installed by individual property owners. Relatively little is known about these private drains because previous studies have concentrated on the larger city storm drain system (Tetra Tech 1988d).

TABLE 3. IDENTIFICATION OF INDICATOR CHEMICALS IN NORTH HARBOR ISLAND PROBLEM AREA SEDIMENTS

Compound	Largest Enrichment Ratio	Number of Historical Analyses with Ratio >1	Number of PTI and Tetra Tech (1988) Analyses with Ratio >1	Total No. of Analyses with Ratio >1	Number of Samples Analyzed[a]	Percent of Samples with Ratio >1
Metals						
Arsenic	6.6	3	1	4	19	21
Copper	9.1	5	1	6	20	30
Lead	3.2	2	1	3	20	15
Mercury	34	13	3	16	20	80
Zinc	12	7	1	8	20	40
LPAH						
LPAH (total)	1.6	1	1	2	20	10
Acenaphthene	1.9	1	1	2	20	10
Fluorene	2.4	2	1	3	20	15
Phenanthrene	2.5	2	1	3	20	15
Anthracene	2.0	2	1	3	20	15
HPAH						
HPAH (total)	10	4	2	6	20	30
Fluoranthene	3.2	3	2	5	20	25
Pyrene	46	7	1	8	20	40
Benzo(a)anthracene	2.5	2	1	3	20	15
Chrysene	3.1	1	3	4	20	20
Benzo(b&k)fluoranthene	3.7	1	2	3	20	15
Benzo(a)pyrene	6.3	1	1	2	20	10
Indeno(1,2,3-cd)pyrene	9.7	1	3	4	20	15
Dibenzo(a,h)anthracene	12.6	0	1	1	20	5
Benzo(g,h,i)perylene	7.3	1	1	1	20	5
4,4'-DDD	60	0	1	1	10	10
Total PCBs	31	16	4	20	20	100
Butyl benzyl phthalate	1.1	0	1	1	10	10
2,4 - dimethylphenol	7.2	4	DL>AET[b]	4	8	50

[a] Station E4 was sampled in 1982 and 1983, and both samples are included in the number of samples analyzed.

[b] Method detection limit for one of four samples exceded cleanup goal.

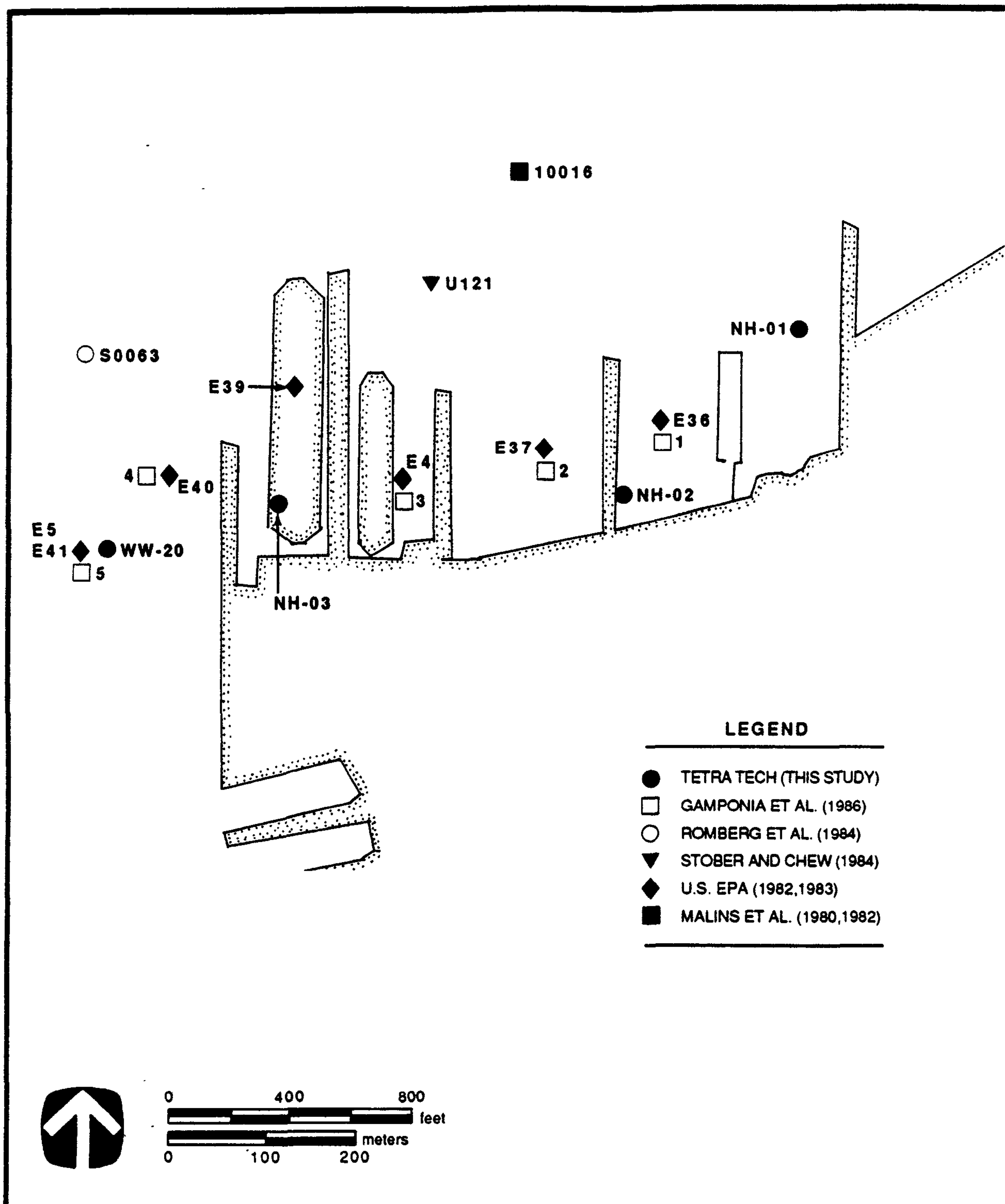

Figure 15. Locations of sampling stations from historical studies of sediment chemistry in the North Harbor Island problem area.

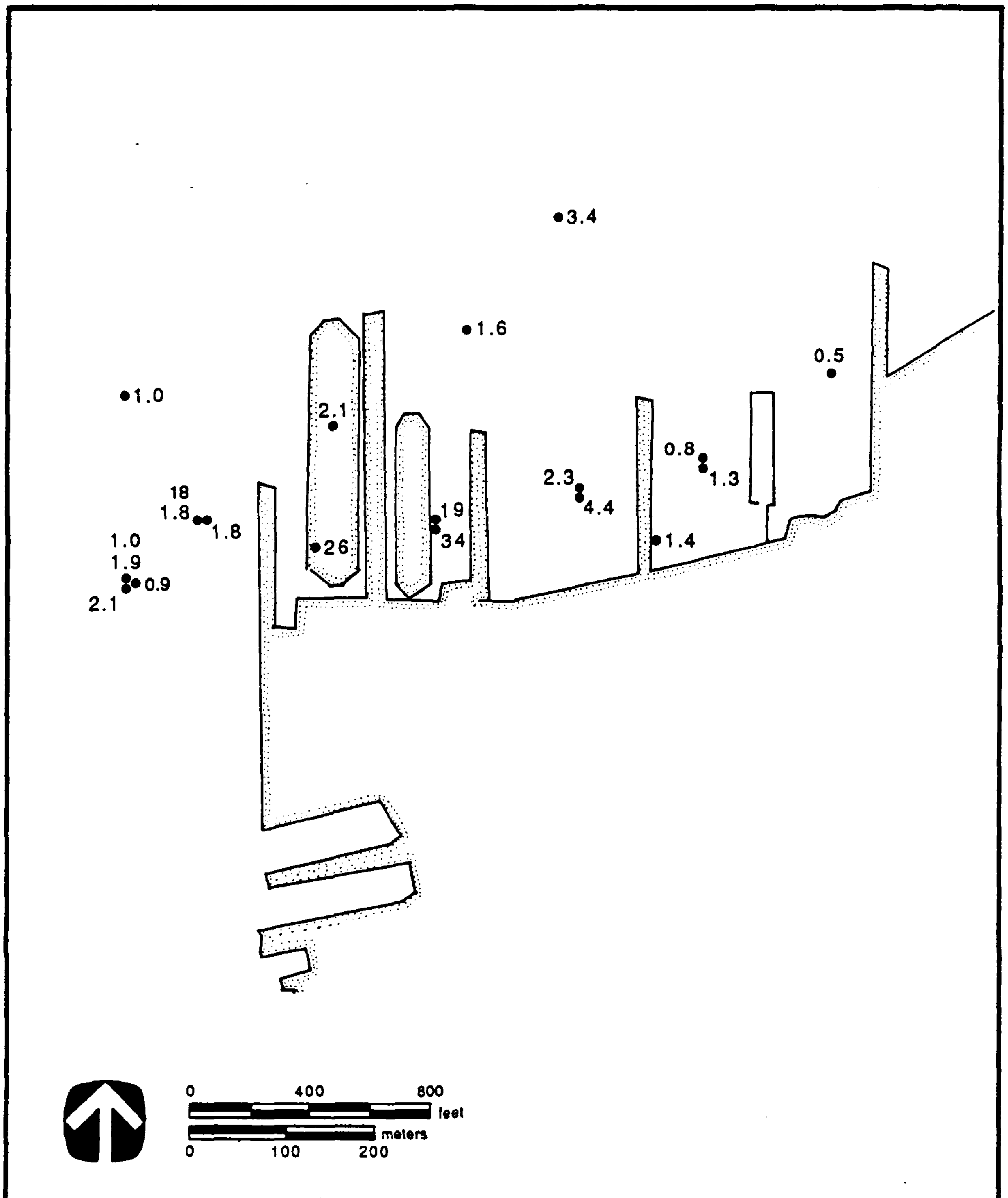

Figure 16. Areal distribution of mercury concentrations in North Harbor Island surficial sediments, normalized to the target cleanup goal (C_O/C_G).

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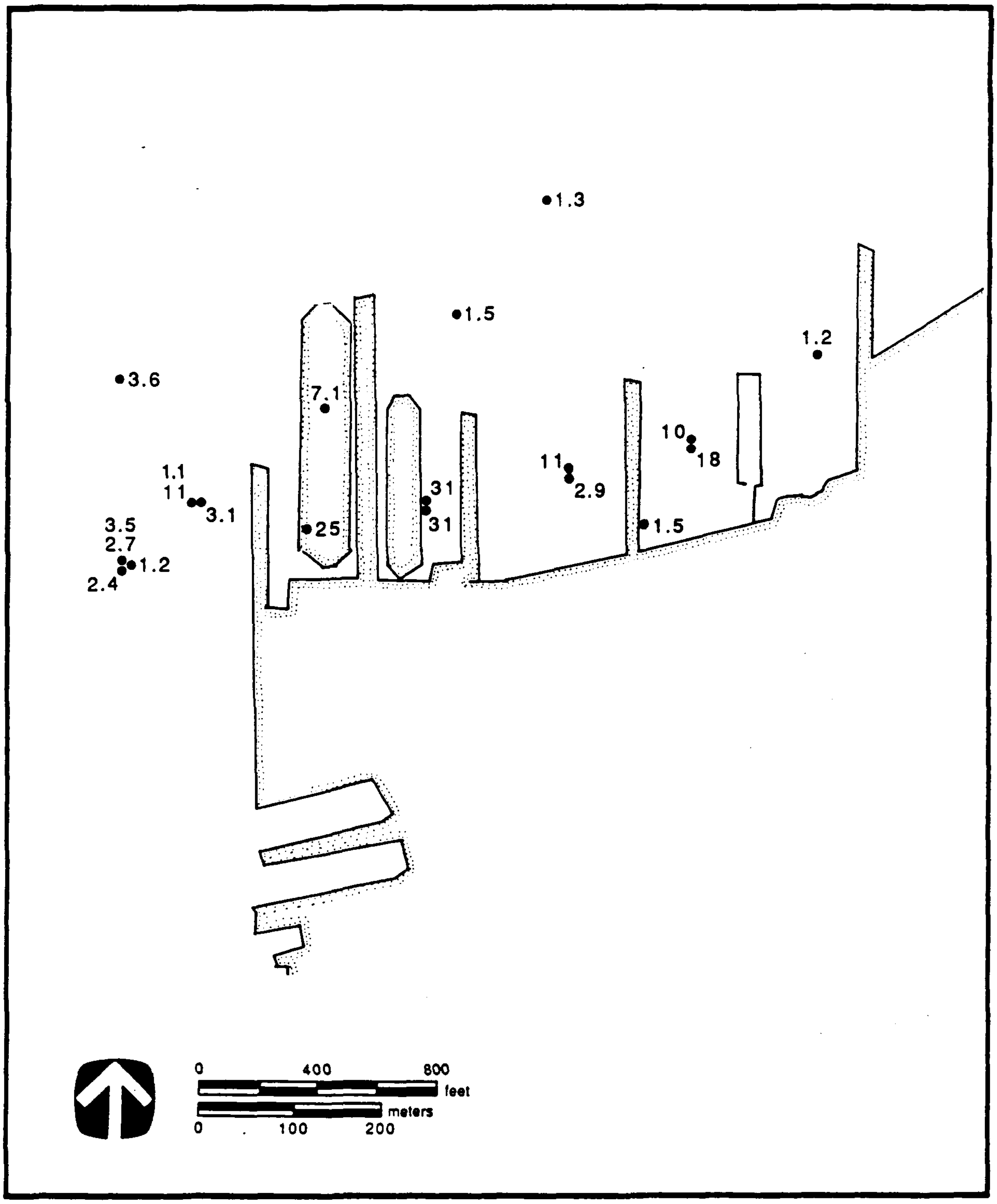

Figure 17. Areal distribution of total PCB concentrations in North Harbor Island surficial sediments, normalized to the target cleanup goal (C_O/C_G).

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There is only one city drain [11th Avenue SW CSO/storm drain (SD) 077] that discharges into the area selected for evaluation of sediment remedial alternatives (Figure 14). The 11th Avenue SW CSO/SD serves a 37 ac area located in the northeast corner of Harbor Island. Numerous private drains discharge into Elliott Bay along the north end of Harbor Island (Figure 14).

A sediment sample was collected near the mouth of the 11th Avenue CSO/SD during the Elliott Bay Action Program source sampling program during 1985 (Tetra Tech in preparation). Sediment from this drain exceeded HAET values for cadmium and lead. In addition, organic compounds identified as problem chemicals in this drain included PAH, PCB, 4-methylphenol, DDT, fluoranthene, and indeno (1,2,3-c,d)pyrene (Tetra Tech in preparation).

Specific sources of cadmium and lead in the 11th Avenue CSO/SD basin have not been documented (Tetra Tech in preparation). There are two facilities in the area (a tugboat company and a bulk petroleum storage facility) that are included in Comprehensive Environmental Response, Compensation, and Liability (CERCLIS). Metals are included as a waste category for these sites (U.S. EPA, 22 October 1987, personal communication).

Todd Shipyards has owned and operated a shipbuilding and repair business on North Harbor Island since approximately 1918. From 1918 until 1952, the shipyard operated a repair facility, which included activities ranging from steel/hull repair, machining, blasting, and painting. In 1952, Todd Shipyards constructed shipbuilding ways and began building ships. In 1983, the shipyard erected a recyclable steel shot blasting and coating facility, and discontinued using copper slay blasting material (Cargill, D., 27 April 1988, personal communication).

Solvents, acids, caustics, oils, oil/water mixtures, and paints have been identified as waste streams generated at the Todd facility. Heavy duty marine coatings, including primers/anticorrosives containing lead chromates and coal tar derivatives, anti-foulings high in copper content, and oil-based alkyd type finishing enamels have been used at the site. According to Metro (1983), shipyards along the Duwamish River have purchased slag from a copper smelter in British Columbia. The copper content of this slag is reported to be approximately 1,000 mg/kg (Dexter et al. 1981).

The feasibility of source control at the North Harbor Island problem area has not been determined. A remedial investigation to be conducted as part of the Harbor Island Superfund Phase I Remedial Investigation is scheduled to begin during the summer of 1988. The remedial investigation and subsequent feasibility study will define the nature and extent of contamination and provide for implementation of source control and cleanup of contaminated areas. The primary reason for not considering the entire NHI problem area (Figure 3) in the area selected for evaluation of sediment remedial alternatives (Figure 2) is the anticipated implementation of source control.

3.2.4 Source Control and Sediment Recovery

The relationship between source control and accumulation of contaminants in the North Harbor Island problem area sediments was evaluated through application of SEDCAM. The model and results for two Elliott Bay problem areas (Denny Way and Slip 4) are reported in full in Tetra Tech (1988c). Key variables are presented in Section 3.1.4.

Sediment depositional parameters in the North Harbor Island problem area have not been characterized to date. Application of the model to this problem area is likely to be inconclusive until sedimentation rates are available. Two sedimentation rates (2.0 and 1.0 cm/yr) were selected for the model to provide a range in possible sediment recovery scenarios for this area. Deposition of sediment from the Duwamish river offshore of North Harbor Island may result in higher sedimentation rates than those selected for the model. The lower rate is conservative and results in the longest sediment recovery time. A mixing depth of 10 cm was selected for the model based on sediment profiles from cores collected in Commencement Bay (Tetra Tech 1987a) and other central Puget Sound shallow bays (Carpenter et al. 1985). Losses due to biodegradation and diffusion were assumed to be negligible. The model was applied to the indicator chemicals mercury and total PCBs. The enrichment ratio for 4,4'-DDD was also included to provide the most conservative estimate for sediment recovery.

Results of the model application to the North Harbor Island problem area are shown in Figure 18 and are summarized below:

- At a sedimentation rate of 1.0 cm/yr, acceptable sediment concentrations (i.e., below cleanup goals) of the indicator chemicals and 4,4'-DDD will not be achieved until about 40 yr after all contaminant loading has been eliminated

- Acceptable surface sediment concentrations are predicted to be achieved within 20 yr at a sedimentation rate of 2.0 cm/yr.

The recovery times predicted above are based on the assumption that 100 percent of the sources have been controlled, including those contributing contaminants to the sediment load of the Duwamish River. Control of all sources contributing contaminants to this area may be infeasible in the near future, and therefore, the recovery times shown above are optimistic.

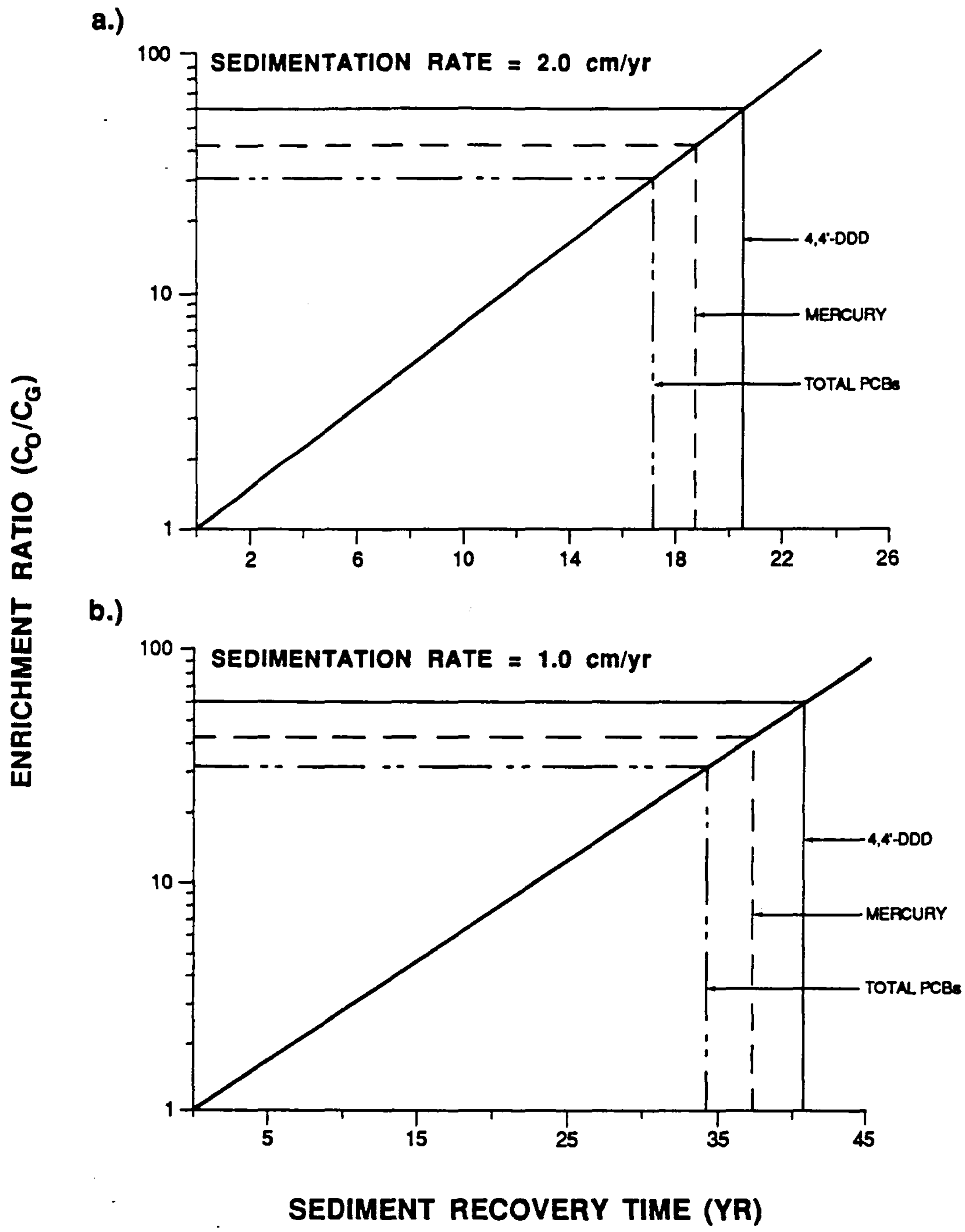

Figure 18. Sediment recovery model results for the North Harbor Island problem area: enrichment ratio based on maximum concentration vs. sediment recovery given 100 percent source control for sedimentation rates of 2.0 cm/yr (a) and 1.0 cm/yr (b).

4.0 REMEDIAL TECHNOLOGIES

Technologies that are potentially applicable to the remediation of contaminated media (i.e., sediment and contaminated dredge water) in the Elliott Bay study areas are described in this section. These technologies were characterized under the Commencement Bay Feasibility Study (Tetra Tech 1988a). Both source control and sediment remedial technologies need to be evaluated before implementing response actions, as control of contaminant sources is essential to the overall approach to cleanup of problem sediments. An evaluation of potential sources of contaminants in the Elliott Bay study area is discussed in a separate report (Tetra Tech in preparation). The purpose of evaluating sediment remedial technologies is to screen or eliminate from further consideration technologies that are inappropriate based on technical implementability, given the nature and extent of contamination and physical characteristics at a given site. The overall approach to the remediation of a contaminated problem area can be termed a response action. Response actions fall into six general categories: no action, institutional controls, containment, treatment, removal, and disposal.

The consideration of the no action alternative provides a baseline from which to evaluate the effects of responses that directly address the cleanup or isolation of contaminated materials. Institutional controls involve limiting the potential for public exposure to site contaminants by such means as educational programs and site access restrictions. Institutional controls involve source control measures that can be implemented under established effluent permitting programs. This response action involves no cleanup of contaminated sediments. These two approaches to remediation are not discussed in this report except for comparison in evaluating candidate remedial alternatives. Containment response actions involve no cleanup of contaminated sediments. Containment response actions involve capping or installing lateral barriers to isolate contaminants from the environment in situ or to preclude the introduction of additional contamination into

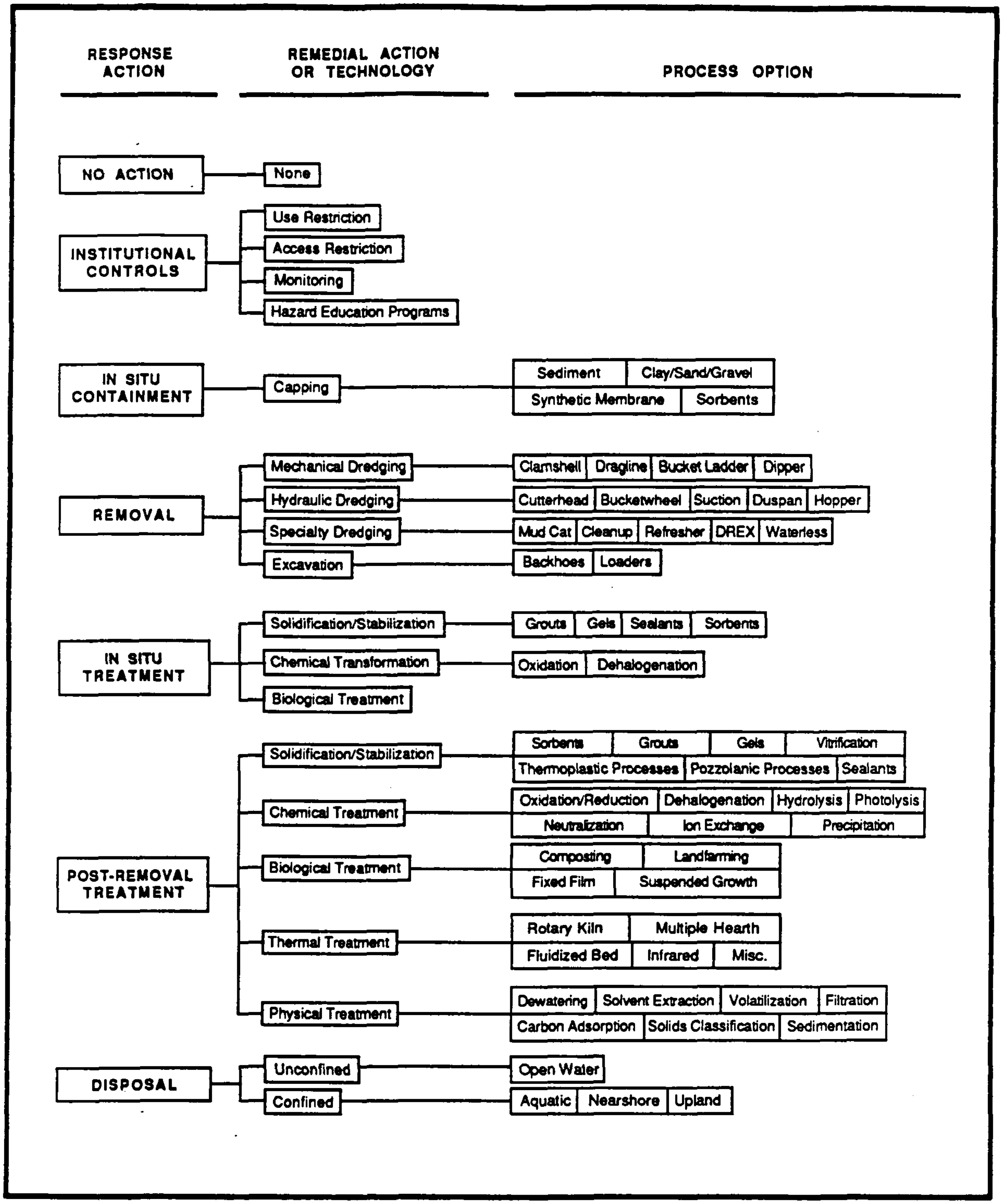

Figure 19. Response action, technology types, and process options for remediation of contaminated sediments.

TABLE 4. SUMMARY OF THE SEDIMENT REMOVAL OPTIONS APPLICABLE TO ELLIOTT BAY

Remedial Action or Technology	Process Option	Technology Retained for Evaluation?	Comments
Mechanical Dredging		Yes	Maintains near in situ density of sediment. Preferable for high metals and volatile organics contamination.
	Clamshell	Yes	Watertight adaptation, medium to large bucket assumed.
	Dragline	No	Only average removal efficiency, high suspended solids.
	Bucket ladder	No	Limited availability, high initial cost, high suspended solids.
	Dipper	No	Relatively high suspended solids, more expensive.
Hydraulic Dredging		Yes	Produces sediment slurry. Unable to remove debris. Preferred for soluble contaminants.
	Cutterhead	Yes	Readily available, dredging depth limited to 50 ft.
	Suction	No	Can only dredge loose, unconsolidated sediments
	Dustpan	No	Not readily available, can only dredge loose sands or gravels.
	Hopper	No	Achieving economically feasible load requires overflow of dredge water.
Specialty Dredging		Yes	Availability, development, experience are needed to fully assess applications and limitations.
Excavation		No	Retained for treatment and disposal (post-removal) applications only.

TABLE 5. SUMMARY OF THE CONTAINMENT AND TREATMENT OPTIONS APPLICABLE TO ELLIOTT BAY

Remedial Action or Technology	Process Option	Technology Retained for Evaluation?	Comments
In Situ Containment			
Capping		Yes	Not feasible in areas requiring maintenance dredging.
	Sediment	Yes	Clean sediment assumed to be available.
	Synthetic membrane	No	Not a proven technology for contaminated sediments.
	Sorbents	Yes	Use of sorbents with other capping material is possible.
Berms and Dikes		Yes	Evaluated as a component technology for capping and disposal alternatives.
In Situ Treatment			
Solidification/Stabilization	(Grouts, gels, sealants, sorbents)	Yes	Evaluated as a component technology for use in conjunction with capping. Conceptual applications considered.
Chemical Treatment	Oxidation Dehalogenation	No	No reports of successful application to contaminated sediments. More than one treatment step would be required for mixtures of organic and inorganic contaminants.
Biological Treatment		No	No reports of successful application to contaminated sediments.

TABLE 6. SUMMARY OF THE POST-REMOVAL TREATMENT OPTIONS APPLICABLE TO ELLIOTT BAY

Remedial Action or Technology	Process Option	Technology Retained for Evaluation?	Comments
Solidification/ Stabilization		Yes	Improved waste handling characteristics, reduced contaminant mobility, alteration of solubility or toxicity of contaminants.
	Sorbents, grouts, gels, sealants	Yes	Proprietary formulations, natural materials, and industrial waste products warrant consideration. No reported applications to CDM.
	Vitrification	No	Energy intensive, potential emission problems. No reported applications to CDM.
	Thermoplastic Processes	No	Very expensive, considerable air pollution potential. No reported applications to CDM.
	Pozzolanic Processes	Yes	Different additives available. Field demonstration for application to CDM would be required.
Chemical Treatment		Yes	Evaluated for management of contaminated dredge water only. No reported applications to CDM.
	Oxidation/ Reduction	No	Oxidants are hazardous. Possible by-product formation and inadequate detoxification are drawbacks to option.
	Hydrolysis	No	Primarily used for carbamate and organophosphorus pesticides.
	Photolysis	No	Primary use is for dioxins and polychlorinated organic compounds.
	Neutralization	No	Used to adjust pH in acidic or alkaline waters. Not applicable to Elliott Bay problem areas.
	Ion exchange	Yes	Salinity will adversely affect performance.
	Precipitation	Yes	Suitable for removing metals in solution.
Biological Treatment		Yes	Availability of suitable disposal site would be determining factor for application of this treatment to CDM. Primary drawback is excessive land use.
	Composting	Yes	Recalcitrant compounds such as PCBs and metals are not treated.
	Land farming	Yes	Degradation of organic constituents must be possible. Cation exchange capacity of soil is limiting factor for metals.

TABLE 6. (Continued)

Remedial Action or Technology	Process Option	Technology Retained for Evaluation?	Comments
	Fixed Film, Suspended growth	No	Waste stream composition must be regulated to ensure biological activity. Recalcitrant compounds not treated. Some metals adsorbed to sludges.
Thermal Treatment		Yes	Retained for treatment of organic compounds. Metals are not removed, energy intensive treatment.
	Infrared, Rotary kiln, Fluidized bed	Yes	Retained as representative technologies.
	Miscellaneous	No	Metals are not removed in treatment process. Potential air pollution problems. Siting of treatment facility questionable.
Physical Treatment		Yes	Potential for isolation and concentration of contaminants in a waste stream. Siting and development of a treatment facility are questionable.
	Dewatering	Yes	Underdrainage in sedimentation basin disposal facility is assumed. Reduces moisture content of CDM.
	Solvent Extraction	Yes	Removes and concentrates organics, precipitates metals.
	Volatilization	Yes	Volatile organic compounds are not anticipated to be a major problem in Elliott Bay CDM.
	Filtration	Yes	Retained for evaluation in removing suspended solids prior to implementing technologies sensitive to suspended solids concentrations.
	Carbon Adsorption	Yes	Proven and effective technology for removal of organic contaminants from aqueous waste. Not a proven technology for CDM.
	Solids Classification	Yes	Potential for reducing volume of CDM requiring treatment. Efficiency of separating contaminated fraction from clean sediment is major consideration for use.
	Sedimentation	Yes	Normally an integral component for removing suspended particulates from hydraulically dredged CDM. Facilitates removal of dredge water.

A summary of in situ containment and in situ treatment technologies retained for further evaluation in the remediation of Elliott Bay problem areas is presented in Table 5. Additional information on capping options is presented in Phillips et al. (1985), U.S. Army Corps of Engineers (1986b), and Tetra Tech (1988a). In situ treatment of contaminated sediments has not been demonstrated. Technologies are being developed for possible in situ treatment of soils, but the application of the technologies to contaminated dredge material (CDM) have not been demonstrated.

A summary of the post-removal treatment technologies for contaminated dredge material (CDM) are presented in Table 6. Demonstration of the applicability of treatment technologies to the remediation of CDM would be necessary prior to implementation. Chemical treatment technologies are retained for use in managing contaminated dredge water only because applications to CDM have not been demonstrated. Additional references for treatment technologies include Data Requirements for Selecting Remedial Action Technology (U.S. EPA 1987), Mobile Treatment Technologies for Superfund Wastes (U.S. EPA 1986b), and Handbook for Stabilization/Solidification of Hazardous Wastes (U.S. EPA 1986a).

4.1 SUMMARY OF PRELIMINARY SCREENING OF SEDIMENT REMEDIAL TECHNOLOGIES

Sediment remedial technologies and process options that passed preliminary screening are illustrated in Figure 20. All response actions applicable to sediment remediation in Elliott Bay were retained. All in situ confinement categories (i.e., berms, dikes, and capping) were retained. However, specific process options were eliminated (i.e., synthetic membranes, sorbents). Cutterhead and closed bucket clamshell dredges were retained for further evaluation as removal technologies. In situ solidification/stabilization processes were considered to be at a conceptual level of development for the treatment of contaminated sediments, and were therefore not explicitly represented during the development of remedial alternatives. They were instead retained as a possible process option to be used in conjunction with in situ containment. Other in situ treatment technologies (e.g., oxidation, dehalogenation, and bioreclamation) were eliminated from further consideration. The post-removal treatment options retained include

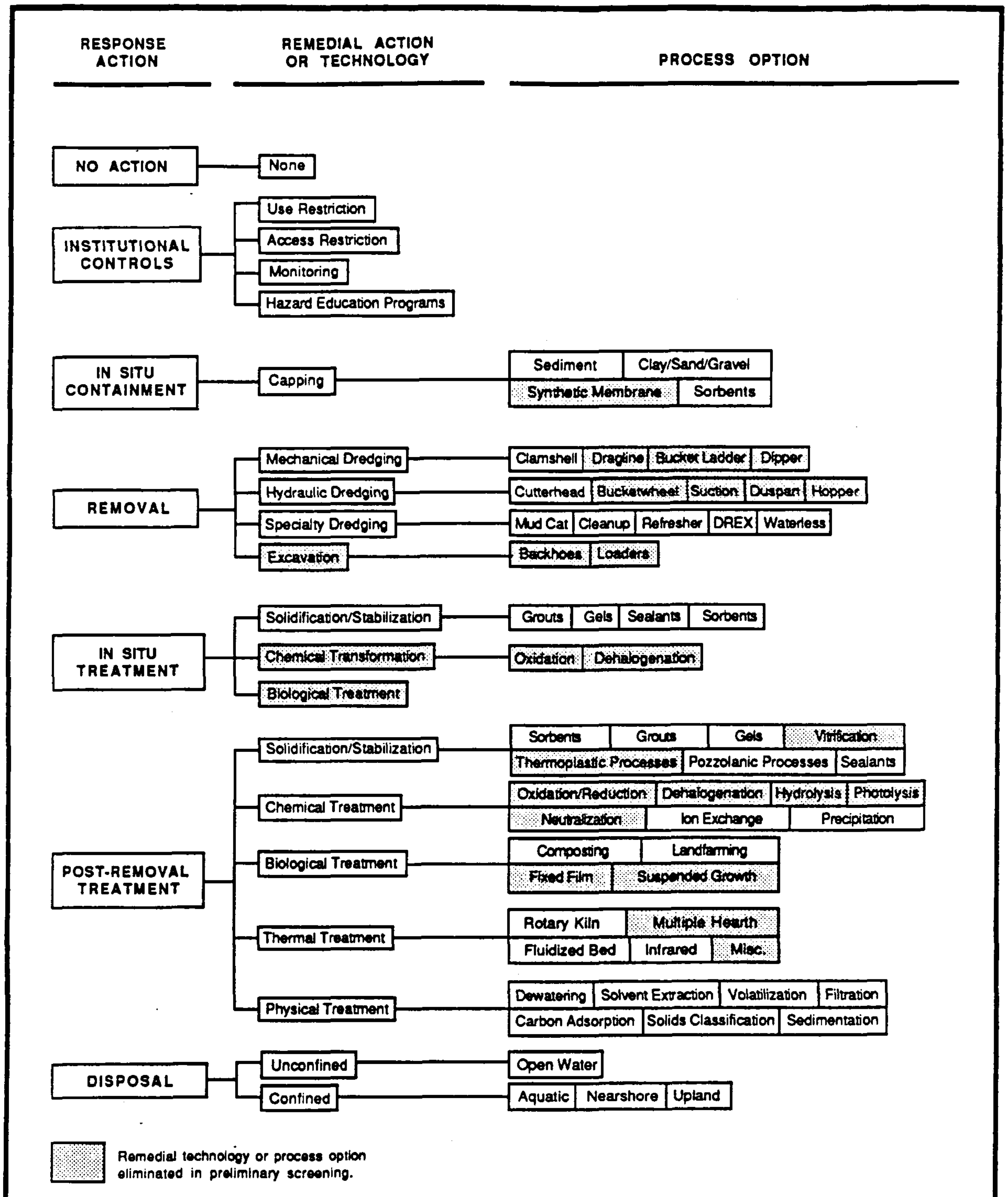

Figure 20. Potential sediment remedial technologies and process options that are retained for further evaluation.

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solidification/stabilization, chemical, biological, thermal, and physical treatment processes. Treatment technologies that address water generated during dewatering (i.e., sorption, ion exchange) were retained, but were not explicitly included in sediment remedial alternatives because their applicability must be determined by bench-scale testing for individual problem areas. Disposal locations retained for further evaluation included unconfined open-water, and confined shallow-water, nearshore, and upland sites. Unconfined open-water sites were considered for treated sediments only.

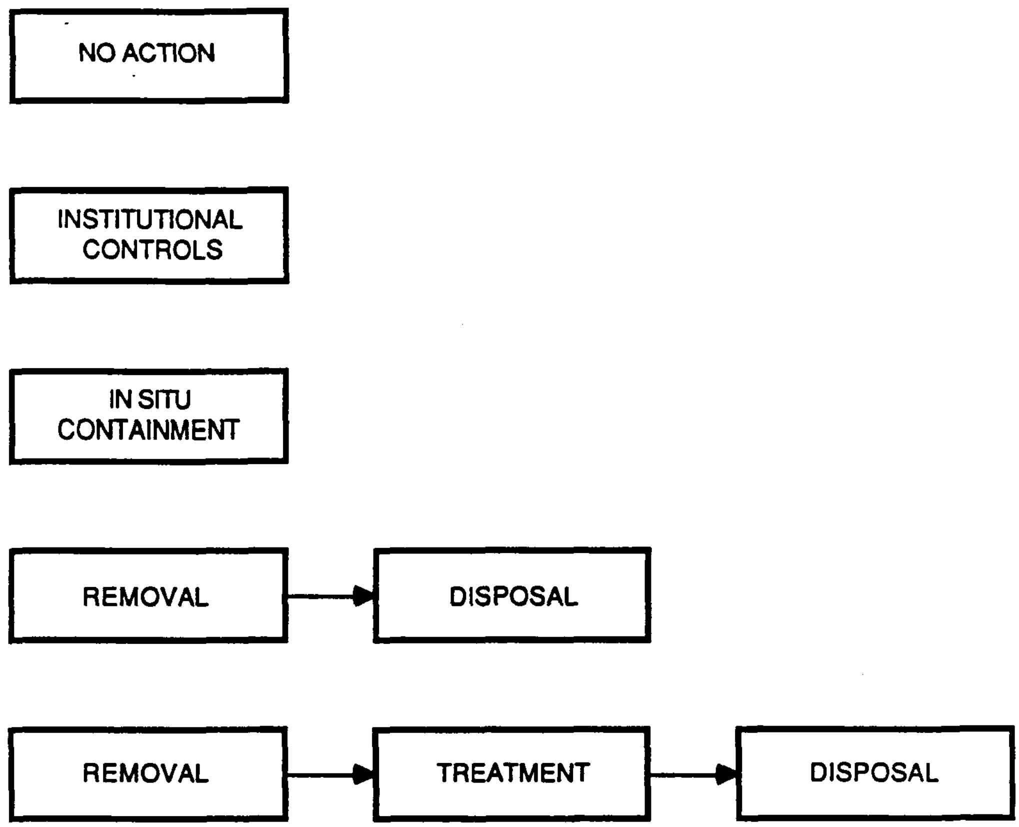
5.0 AREA-WIDE SEDIMENT REMEDIAL ALTERNATIVES

A remedial alternative is a discrete combination of institutional controls and remedial technologies applicable to the cleanup of a contaminated site (Tetra Tech 1988a). In this chapter, area-wide remedial alternatives are presented for Elliott Bay problem area sediments. The development of alternatives is conducted in two steps. The first step is the development of generic alternatives based on the general response actions presented in Figure 19 of Section 4.0. The second step is the identification of specific alternatives from the technology types and process options that are most applicable to sediment remediation in the Elliott Bay area. The objective of Section 5.0 is to obtain a set of remedial alternatives representing all technology types considered suitable for evaluation.

5.1 DEVELOPMENT OF GENERIC SEDIMENT REMEDIAL ALTERNATIVES

As discussed in Chapter 4.0, sediment remedial technologies may be grouped into one of six general response actions: no action, institutional controls, in situ containment, removal, treatment, and disposal. Each response action consists of one or more technology types and associated process options. The possible approaches to sediment remediation based on these six general response actions are represented by the five generic remedial alternatives shown in Figure 21. The simplest alternative is no action; the most complex alternative involves dredging, treatment, and disposal. Costs and the level of permanency generally increase in progressing from no action to alternatives involving dredging and treatment of CDM.

A list of representative technology types and associated process options that passed screening is presented below. These technologies are considered to have the greatest potential for timely and effective remediation of contaminated Elliott Bay sediments.



NOTE: Monitoring is an essential element of all but the 'no action' alternative.

Figure 21. Generic sediment remedial alternatives.

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- Containment
  - Capping
  - Berms and dikes

- Sediment removal
  - Watertight clamshell dredge
  - Pipeline cutterhead dredge
  - Specialty dredge heads
  - Mudcat dredge

- Sediment treatment
  - Solidification/stabilization (pozzolan-Portland cement)
  - Land treatment
  - Incineration (infrared)
  - Dewatering
  - Solvent extraction
  - Filtration
  - Sedimentation

- Disposal
  - Unconfined aquatic
  - Confined aquatic
  - Confined nearshore
  - Confined upland.

5.1.1 Containment

For in situ containment of sediments, capping is the only applicable technology. In the development of a capping alternative, use of uncontaminated dredge material for the cap was assumed, although the use of a different medium could be considered in a more detailed analysis. In situ solidification coupled with capping may be effective but is not evaluated here because the process is not well understood.

5.1.2 Sediment Removal

Hydraulic and mechanical dredging represent the two fundamental approaches to sediment removal. The pipeline cutterhead dredge is the most commonly used hydraulic dredge in the U.S. and the Pacific Northwest, and several modifications for the removal of contaminated sediments have been implemented (Phillips et al. 1985). Although the pipeline cutterhead dredge was selected to represent hydraulic dredging, specialty hydraulic dredges identified in the preliminary screening of dredging technologies should be reconsidered during final design and equipment selection.

The clamshell dredge is the only mechanical dredge retained from preliminary screening. The use of a watertight bucket modification was assumed for development of alternatives involving mechanical dredging. This modification of the conventional clamshell is not expected to affect dredging efficiency and will help decrease the amount of suspended solids generated during dredging.

5.1.3 Sediment Treatment

Several sediment treatment technologies were selected for further evaluation. Of the possible stabilization/solidification process options, only sorbent stabilization, pozzolanic/cement systems, and proprietary materials passed preliminary screening. Pozzolanic/cement systems were identified as the representative process option because they are considered to be the most protective from the standpoint of contaminant immobilization, particularly when the CDM contains particle-associated organic constituents. In some cases, however, stabilization rather than solidification may be adequate for the reduction of contaminant mobility, and will generally be less expensive. Proprietary formulations should also be evaluated during treatability studies to select the most suitable treatment formulation.

No chemical treatment process options were selected for evaluation as part of sediment remedial alternatives, because none were identified as implementable for the treatment of CDM solids. In addition, many of the problem contaminants in Elliott Bay sediments have strong particle affinities and may be substantially removed by the sedimentation process alone. Nonetheless, treatment of dredge water may be necessary to meet water quality criteria. Management of dredge water produced during hydraulic dredging was assumed to involve chemically assisted sedimentation. Mechanical dredging was assumed to result in minimal production of dredge water and negligible treatment costs. The severity of dredge water contamination is determined by the physical and chemical properties of the contaminants and the degree to which they are partitioned between particulate, aqueous, and gas phases. Elutriate testing of CDM is necessary to determine the need for dredge water treatment.

The only biological treatment option suitable for CDM is land treatment. This option is retained for sediments with low concentrations of contaminants that have proven feasible to biodegradation.

Infrared incineration was selected as the representative thermal treatment. Mobile systems with high capacities are available and have been demonstrated to be effective in the treatment of contaminated soils and sludge-like materials.

Within the category of physical treatment, the following process options were selected for further evaluation as components of one or more sediment remedial alternatives:

- Solvent extraction using the B.E.S.T.^{tm} process
- Sedimentation
- Dewatering
- Solids separation
- Carbon adsorption
- Filtration.

The B.E.S.T.^{tm} solvent extraction process is potentially applicable to the removal of hazardous organic contaminants (e.g., PCBs, PAH, chlorinated hydrocarbons, phenols) from CDM. The process essentially concentrates the organics in liquid form, which may then be incinerated at much less expense than incineration of the CDM itself. Sedimentation is essential for the upland disposal of hydraulically dredged sediments, and it may also be necessary, in some cases, for nearshore disposal. Chemical coagulation to remove solids remaining in suspension following primary solids removal is assumed to be included in the sedimentation process option. Dewatering methods, both passive and mechanical, are an essential feature of upland disposal options when Resource Conservation and Recovery Act (RCRA) landfill requirements must be met. Mechanical dewatering is not further evaluated here, but should be considered in a more detailed evaluation of alternatives involving upland disposal of CDM, especially when the volumes are small. In the development of sediment remedial alternatives, passive dewatering in the form of underdrains provided in upland confined systems was assumed. Carbon adsorption is a useful treatment option for contaminated dredge water treatment, although other technologies may be needed in conjunction with this option. Filtration technologies may be useful in combination with other process options as a measure to remove suspended solids.

5.1.4 Disposal

All four disposal options passed preliminary screening. However, unconfined open-water disposal is not considered as part of any alternative, because contaminated sediments dredged from the Elliott Bay problem areas are not likely to be permitted in a designated unconfined disposal site. Unconfined open-water disposal may be a feasible option for treated sediments when the level of contamination has been reduced to below goals that are being established under PSSDA.

5.1.4.1 Disposal Site Availability--

Potential sites for the disposal of Elliott Bay sediments are presently being evaluated under the Puget Sound Dredge Disposal Analysis (PSDDA) program and as part of the Puget Sound Water Quality Management Plan (Puget

Sound Water Quality Authority 1987). Phase I of PSDDA designated sites and established criteria for unconfined open water disposal of dredge material. The scheduled date for adoption of the PSDDA Phase I guidelines by the PSWQA is 1 April 1988. Under Element S-6 of the PSWQA Water Quality Management Plan, Ecology has been tasked with determining the feasibility and needs for multi-user confined disposal sites. The various elements of the PSWQA contaminated sediments and dredging program are scheduled for completion from 1988 to 1991. The sites designated in this report may or may not be available for use, depending on institutional considerations of PSDDA and PSWQA.

A listing of potential disposal sites available for dredge material disposal, their estimated capacity, and land ownership is presented in Table 7. The use of the different sites will depend on several factors, including contaminant characteristics, possible future uses for the sites, and the party performing the removal and disposal.

Open-Water Sites--

Sites and criteria for dredge material characteristics that are suitable for unconfined open water disposal in Elliott Bay have been designated under PSDDA Phase I studies. The preferred and alternate unconfined open-water disposal sites in Elliott Bay are shown in Figure 22. The capacity of the unconfined open-water site is projected to be sufficient for dredging projects in Elliott Bay through the year 2000. Actual volumes of sediment suitable for disposal will depend on the management conditions adopted for the site (PSDDA 1988).

One possible site for confined aquatic disposal is the East Waterway (Figure 22). Several depressions are present in the waterway which could be filled with contaminated dredge material and capped. Considerations for the future use of the East Waterway, the need to accommodate increasing ship sizes, and the designation of the East Waterway as a problem area all decrease the possibility of using this waterway for confined aquatic disposal.

TABLE 7. POTENTIAL DREDGE MATERIAL DISPOSAL SITES FOR ELLIOTT BAY

Potential Site	Land Ownership/Steward	Estimated Capacity (1,000 yd^3)
Open Water Unconfined		
PSDDA Phase I	State of Washington/ Department of Natural Resources	3,113-6,162[a]
Confined Aquatic		
East Waterway	State of Washington/ Department of Natural Resources	250
Nearshore		
Slip 25	Port of Seattle	175-200[b]
Terminal 91	Port of Seattle	800-1,000[b]
Upland		
Coal Creek	Rabanco	15,000
Cedar Hills	King County	80,000

[a] Total forecasted dredging volume that could be discharged at unconfined Elliott Bay site. Actual volumes to be discharged at the open-water unconfined site will vary depending on site management condition adopted (PSDDA Phase I Draft EIS).

[b] The actual capacity will vary depending on berm and cap thickness.

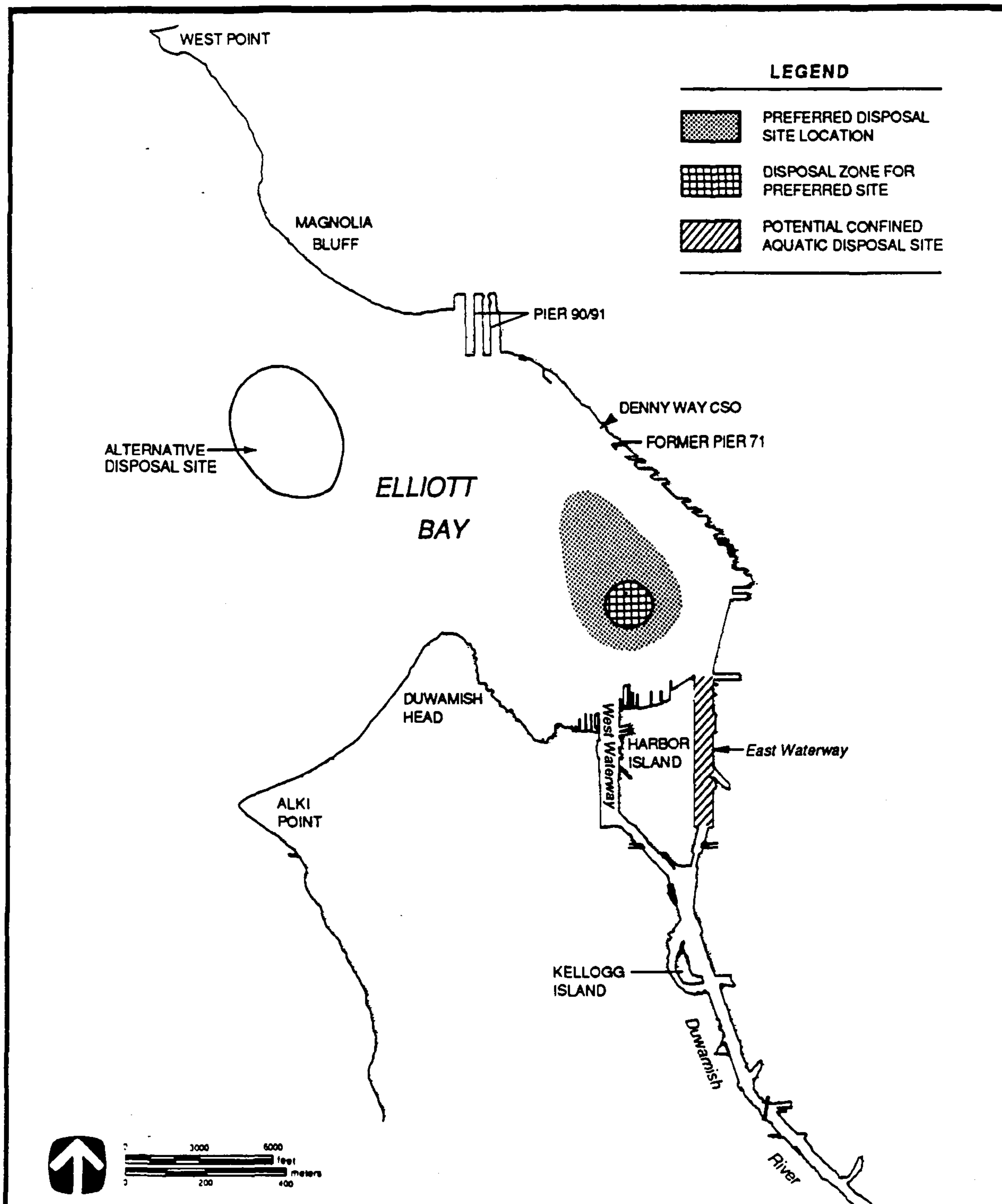


Figure 22. PSDDA preferred and alternate unconfined open water disposal sites in Elliott Bay and potential confined aquatic disposal site.

Nearshore Sites--

Potential nearshore sites for the disposal of contaminated dredge material are shown in Figure 23. Actual capacity of the nearshore sites (Table 7) will depend on engineering considerations (i.e., cap and berm thickness). Priority for dredge material disposal at the Pier 91 and Pier 27 sites would be given to Port of Seattle dredging projects. Disposal of CDM at either of the two sites by parties other than the Port of Seattle may not be feasible due to capacity constraints following use by the Port of Seattle. The use of the two nearshore sites for disposal will also depend on future planning by the Port of Seattle for these two areas. If expansion of Piers 90-91 is needed for Port of Seattle growth, then nearshore disposal of CDM in this area may become a more feasible alternative.

Upland Sites--

Municipal landfills and privately owned construction debris landfills present limited opportunities for upland disposal. The Seattle-King County Health Department is responsible for making the final decision on the suitability of material for landfill disposal. At present, material containing up to 10 percent dangerous waste may be disposed of in the Coal Creek landfill. However, the 10 percent dangerous waste criteria is currently undergoing revisions for individual compounds (Burke, S., 13 April 1988, personal communication). Materials that do not meet the PSDDA criteria for open water disposal (problem wastes) would not be accepted for landfill disposal without prior treatment due to liability issues. Problems experienced by the Port of Seattle with sediments landfilled in West Seattle, which required subsequent removal due to hazards posed to the community, serve to illustrate liability issues associated with landfill (or construction site) disposal of CDM. Acquisition of land, engineering and construction of an upland disposal facility is one possibility. However, development of an upland facility within a reasonable transportation distance (approximately 3 mi for hydraulically dredged material or 20 mi for dewatered sediment) would likely be difficult from a public acceptance and cost-effectiveness standpoint. The following sites were identified as potential upland disposal facilities. Additional rural landfills (i.e., Vashon,

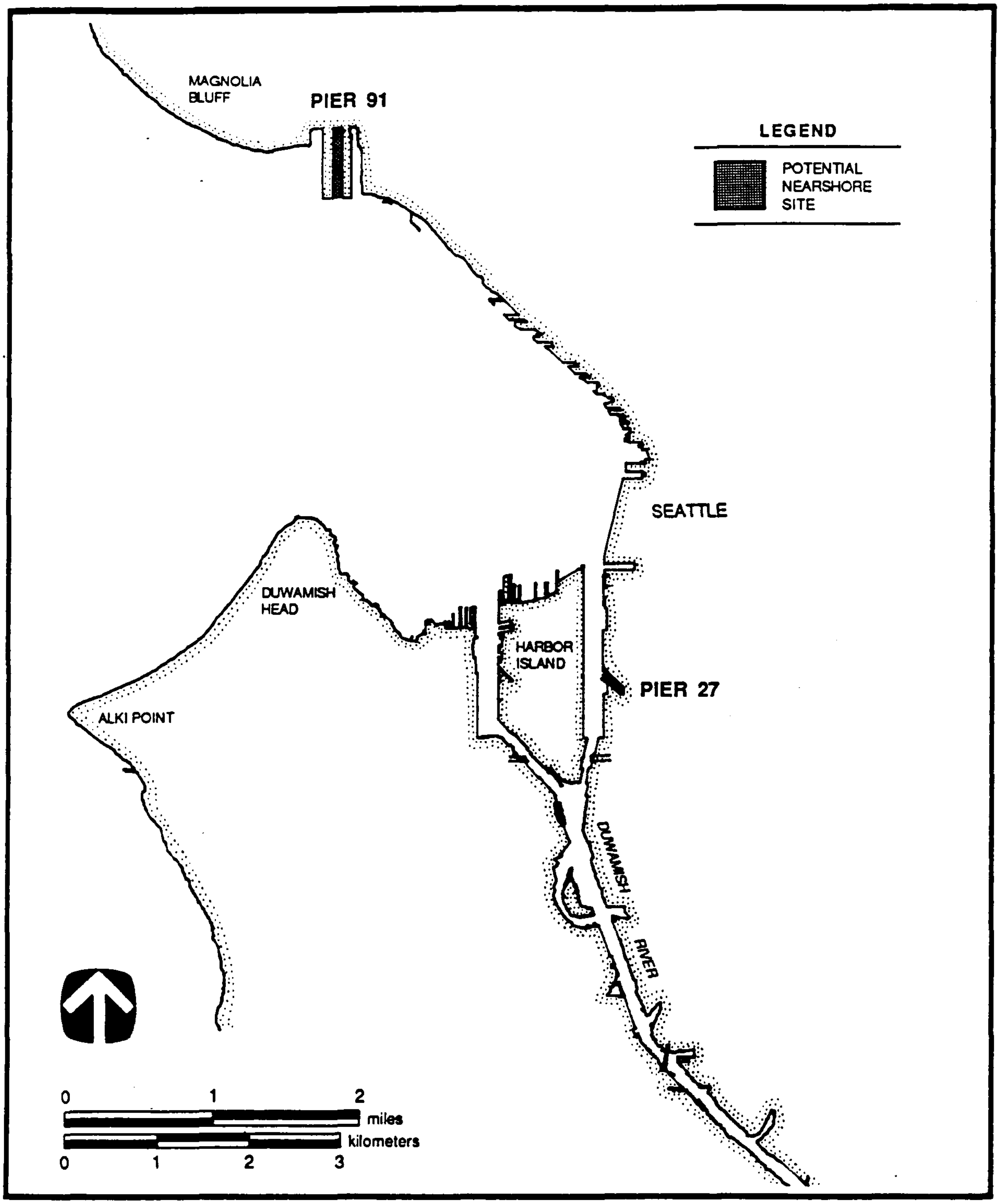


Figure 23. Potential nearshore sites for disposal of contaminated sediments in Elliott Bay.

Hobart) have only limited capacity or are undergoing closure, so they were not considered.

Coal Creek--This privately owned construction debris landfill is located approximately 15 mi east of Seattle. The large capacity (i.e., 15,000 yd^3) of the landfill makes it suitable for dredging projects of any scale. Siting and construction of a treatment facility for dewatered sediment would be one possible option for disposal of CDM. However, bench-scale testing of the treatment system would be required.

Cedar Hills--This regional landfill is located approximately 12 mi south of Seattle. Dewatering or solidification/stabilization and treatment of CDM would be required prior to disposal. Mitigation of additional traffic impacts associated with disposal would also require consideration.

RCRA Facilities--Two RCRA landfills operate in U.S. EPA Region X. Chemical Securities operates a minimum technical standards landfill under interim permit status at its Arlington, OR facility. Envirosafe Services of Idaho operates a facility near Grandview, ID, which is also under interim status. Neither firm currently has a stabilization capability. Offsite RCRA landfill should be considered as a reserve option only, in keeping with the U.S. EPA's offsite disposal policy.

5.1.4.2 Transportation--

Several methods are available in Puget Sound to transport sediments from the Elliott Bay study area. The most practical choice will be dictated by the dredging method and access to the disposal site. Sediments removed by hydraulic dredge can most efficiently be transported by pipeline to a nearshore, upland, or aquatic disposal site, if distances between the dredge and disposal sites are only a few miles. Sediments removed by clamshell dredge will have nearly in situ densities. Such sediments can be transported by split-hulled barge to nearshore and aquatic disposal sites and by truck, rail, or barge to upland disposal sites.

5.2 IDENTIFICATION OF CANDIDATE SEDIMENT REMEDIAL ALTERNATIVES

The generic alternatives and sediment remedial technologies identified above were combined to form the set of area-wide sediment remedial alternatives presented below:

- No action
- Institutional controls
- In situ capping
- Removal with hydraulic dredge/confined aquatic disposal
- Removal with hydraulic dredge/nearshore disposal
- Removal with hydraulic dredge/upland disposal
- Removal with hydraulic dredge/solidification/upland disposal
- Removal with clamshell dredge/confined aquatic disposal
- Removal with clamshell dredge/nearshore disposal
- Removal with clamshell dredge/incineration/upland disposal
- Removal with clamshell dredge/solidification/upland disposal
- Removal with clamshell dredge/solvent extraction/unconfined disposal
- Removal with clamshell dredge/land treatment.

Each alternative represents a plausible combination of remedial actions designed to meet the objectives of the Elliott Bay sediment remediation effort. The set as a whole encompasses the range of generic alternatives and adequately represents all viable remedial action technologies. The effectiveness, implementability, and costs of viable alternatives are evaluated for two problem areas (Section 7.0). Descriptions of each of the above alternatives are presented in the remainder of this section.

5.2.1 No Action

The no action alternative supplies a baseline against which other sediment remedial alternatives can be compared. Under the no action alternative, the site would be left unchanged, with no remediation of sediment contamination. This alternative does nothing to mitigate the public health and environmental risks associated with the site. Absence of source control is an implicit element of this alternative. Potential impacts of the no action alternative include the persistence of the following observed environmental effects in Elliott Bay:

- Exceedance of AET for problem chemicals
- Acute toxicity of sediments
- Bioaccumulation
- Depressions of the benthic communities
- Histopathological effects on fish
- Increase in liability for environmental damage.

5.2.2 Institutional Controls

Institutional controls include access restrictions, limitations on recreational use of nearshore areas, issuance of public health advisories, monitoring, and most importantly, control of contaminant sources. Limitations on access and recreation, such as fishing and diving, limit human exposure and reduce risk to public health, but do nothing to mitigate the environmental impacts mentioned under the no action alternative. Some degree of long-term mitigation may be expected from reductions in source loadings. The effect of source control on contaminant loadings and on natural recovery of sediments is discussed in Tetra Tech (1988c). Monitoring identifies contaminant migration patterns and areas of new or increased contamination, and allows changes in risks assessment to public health and the environment before major impacts are realized. In addition, monitoring can be used to validate or refine estimates of the success of source control based on the natural ability of sediments to recover.

5.2.3. In Situ Capping

In situ capping can substantially reduce the risks of environmental exposure to sediment contaminants. The capping material may be clean dredged material or fill (e.g., sand). In addition, it may be feasible to include additives (e.g., bentonite) to reduce hydraulic permeability of the cap or sorbents to inhibit contaminant migration. The use of in situ sediment stabilization techniques as a component of an overall capping strategy may further reduce the potential for migration of contaminants.

Both mechanical and hydraulic dredging equipment can be used for in situ capping operations. Cohesive mechanically dredged material would be placed at the disposal site by using a split-hulled barge. Hydraulically dredged material would be placed at the disposal site by using a downpipe and diffuser. Depending on site topography, diking may be necessary along a margin of the capped sediments to provide lateral cap support.

In situ capping as a sediment remedial alternative has the advantage of preserving the original physicochemical conditions of the problem sediments. This limits the potential for metals mobilization, which can result from bringing predominantly anaerobic sediments into an aerobic environment during dredge and disposal operations. Furthermore, contaminant redistribution from the resuspension of sediments during dredging is avoided. In situ capping is a proven technology, with completed projects in areas from the Long Island Sound and New York Bight Apex (Sanderson and McKnight 1986) to the West Waterway in Elliott Bay (Truitt 1986).

Capping is inappropriate for environments with a high potential for ship scour, currents, or wave action, because these disturbances can lead to cap erosion. The potential for erosion due to shipping activities requires additional study for areas under serious consideration for capping. Maintenance dredging requirements for waterway channels may preclude the use of this alternative in areas maintained for shipping (i.e., East and West waterways). Capping should not be considered under circumstances in which contaminant sources cannot be sufficiently controlled, and ongoing contaminant inputs are likely to result in renewed depressions of benthic communities following capping.

For the purposes of evaluating the capping alternative and estimating costs, it was assumed that clean dredged material would be used to construct the cap. The capping material would be dredged using a clamshell to maintain cohesiveness, transported to the problem area in a split-hulled barge, and then deposited to create a cap a minimum of 3 ft thick.

5.2.4. Removal with Hydraulic Dredge/Confined Aquatic Disposal

As with in situ capping, confined aquatic disposal (CAD) can substantially reduce environmental exposure to sediment contaminants. In the CAD alternative, contaminated sediment is dredged from one location using a hydraulic dredge and then confined subaquatically at a different location. The CAD options described in Section 4.0 differ from one another based on depth and site physical characteristics. Hydraulic and mechanical dredging, as well as hydraulic and split-hulled barge placement techniques, can be used to implement CAD alternatives.

One drawback to CAD is that dredging destroys existing benthic habitat and can result in the redistribution of contaminated sediments. There are fewer monitoring and site controls available for the CAD option versus upland or nearshore disposal sites.

Four CAD approaches (deep-water mound, deep-water confined, shallow-water confined, and waterway confined) are described by Phillips et al. (1985). Of these, the deep-water, and waterway CAD approaches appear to be the most suitable for sediment remediation in Elliott Bay. Shallow-water disposal sites have not been identified, and they are considered to be less protective because of proximity to the water surface and potential erosion of the containment structure due to wave action. Deep-water disposal siting is also uncertain. Potential CAD sites are presently being investigated for the Puget Sound Water Quality Management Plan (Puget Sound Water Quality Authority 1987) by Ecology. The waterway CAD option is feasible and has the advantage of retaining the contaminated sediments at in situ conditions. A capping project in the Duwamish waterway conducted by the U.S. Army Engineers (Truitt 1986) has demonstrated the effectiveness of the capping technique over the short term.

One possible alternative for the East Waterway problem area (Figure 3) is confinement of the CDM within the waterway itself. This alternative would entail dredging an area well below the zone of contamination, depositing CDM in the excavated pit, and capping the CDM with clean dredged material. This approach has been evaluated for problem areas in Commencement Bay, however, a deep-water confined site was selected as the preferred alternative because of concerns over future channel dredging projects and the bulking of material following dredging.

For the purpose of evaluating the waterway CAD alternative, a cellular implementation approach was assumed. This approach involves establishing an imaginary grid over the problem area to permit operations on one grid cell at a time. Hydraulic dredging equipment would be used to dredge contaminated sediments from the initial cell. The sediments would be placed in a deep-water CAD unit. Underlying clean sediments would be removed from the first cell and either temporarily stockpiled for later use, used as capping material, or disposed of at an unconfined open-water site. Once excavation to the predetermined depth was reached, the transfer of contaminated sediments from an adjacent cell into the first cell would begin. A downpipe would be used for hydraulic placement of the contaminated CDM. Clean sediments from the second cell would then used to form a cap at least 3 ft thick over the CDM in the first cell. This cycle would continue until all problem area contaminated sediments had been confined.

5.2.5 Removal with Hydraulic Dredge/Nearshore Disposal

Dredging followed by confined disposal in the nearshore environment is another possible alternative for sediment remediation in Elliott Bay. Generally, nearshore sites need to be diked before they can receive dredged material. There are essentially no limitations in the selection of dredging and transport equipment although hydraulic dredging followed by pipeline transport to the disposal facility is considered optimal (Phillips et al. 1985). Hydraulic dredging confines dredged material to a pipeline during transport, thereby minimizing exposure potential and handling requirements. Systems for management and treatment of dredge water can readily be incorporated into the facility design. Mechanical dredging with transport by split-hulled barge may prove to be a more feasible alternative when pipeline transport interferes with waterway uses.

Confined nearshore disposal permits a greater degree of control in both the design and construction of the confinement system than does CAD. In addition, monitoring efforts are easier to implement. Installation of monitoring equipment along the perimeter of a nearshore confinement facility permits the detection of contaminant migration through the dikes, a much smaller physical structure to monitor than a vast subaquatic cap. Monitoring combined with physical maintenance and routine inspections results in improved long-term integrity of the confinement system. Appropriate dike construction would be necessary to mitigate the effects of waves in eroding the confining materials.

The primary environmental impact associated with implementation of this alternative is the loss of existing benthic habitat at the dredge site and the loss of intertidal habitat at the disposal site. Because of the intertidal location of the disposal site and the high value placed on intertidal habitat, this alternative would require a habitat mitigation component. Also, the influence of tides and groundwater on contaminant transport is much greater for nearshore confinement than for CAD or upland disposal. In addition, altered redox conditions may increase the mobility of metals.

For the purpose of evaluating this alternative, it was assumed that a nearshore disposal facility would be located within approximately 3 mi of the dredging site, thereby facilitating transport of the CDM. A cutterhead hydraulic dredge and pipeline transport system would be used. Because of the low solids content of hydraulically dredged sediments (15-25 percent solids by volume), management of dredge water would be required. In this case, dredge water would be clarified to remove suspended solids prior to discharge to the marine environment. A chemical coagulant addition system and secondary settling basin similar to that described by Schroeder (1983) are included as an element of this remedial alternative.

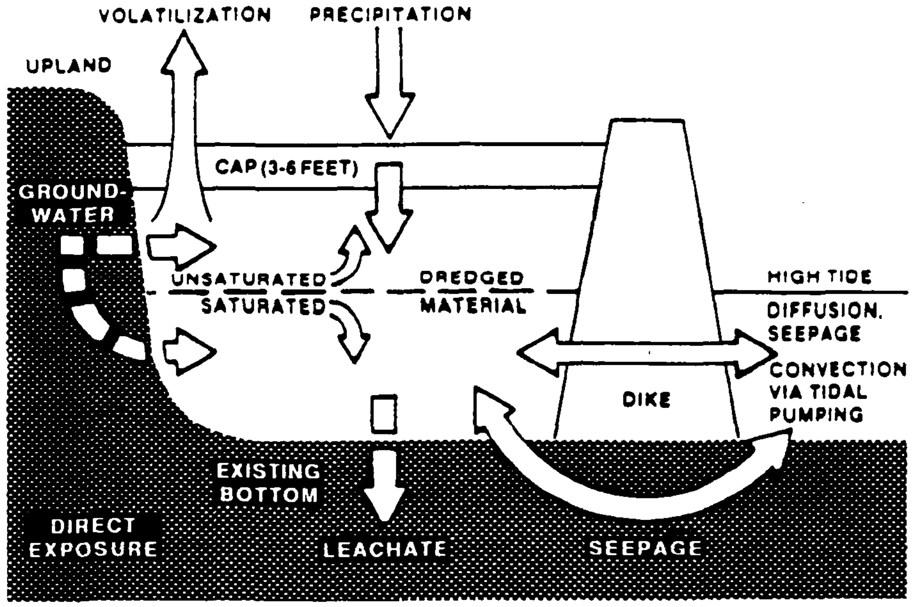
A schematic depicting general features of a nearshore disposal facility is presented in Figure 24. To accommodate a dredge water control system using chemical coagulation, the secondary settling basin would resemble the system illustrated in Figure 25. Other design features that were assumed for the purpose of estimating construction costs include the absence of a liner, a fill depth of 30 ft, and cap thickness of 3 ft.

5.2.6. Removal with Hydraulic Dredge/Upland Disposal

Dredging followed by upland disposal involves the transfer of CDM to a confinement facility that is not under tidal influence. Sediment would be dredged either mechanically or hydraulically and transferred to the disposal site by truck, rail, or pipeline. As in the case of nearshore disposal, provisions would be made for the management of dredge water.

Upland disposal of CDM provides for the greatest level of contaminant control in the absence of treatment. Design features would include installing a liner and cap. The liner system could include an underdrainage for dewatering the fill material and for controlling leachate over the long-term. The underdrainage would be designed to operate as either a passive collection system or a vacuum-assisted dewatering system.

The primary environmental impact of this remedial alternative would be the destruction of existing benthic habitat at the dredging site. As with all alternatives that involve dredging, resuspension of contaminated



NEARSHORE DISPOSAL

Reference: Phillips et al. (1985).

Figure 24. General features of confined nearshore disposal site.

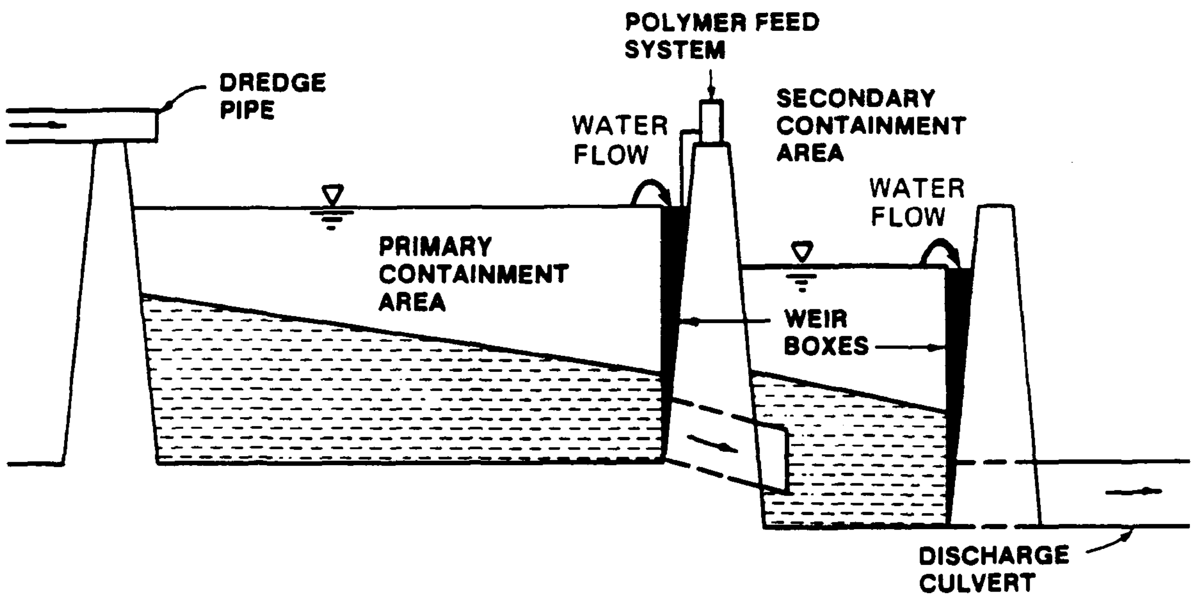


Figure 25. Dredge water chemical clarification facility.

sediment would also be a concern. In contrast to the nearshore disposal option, the destruction of habitat at the upland disposal site is unlikely to be as environmentally significant.

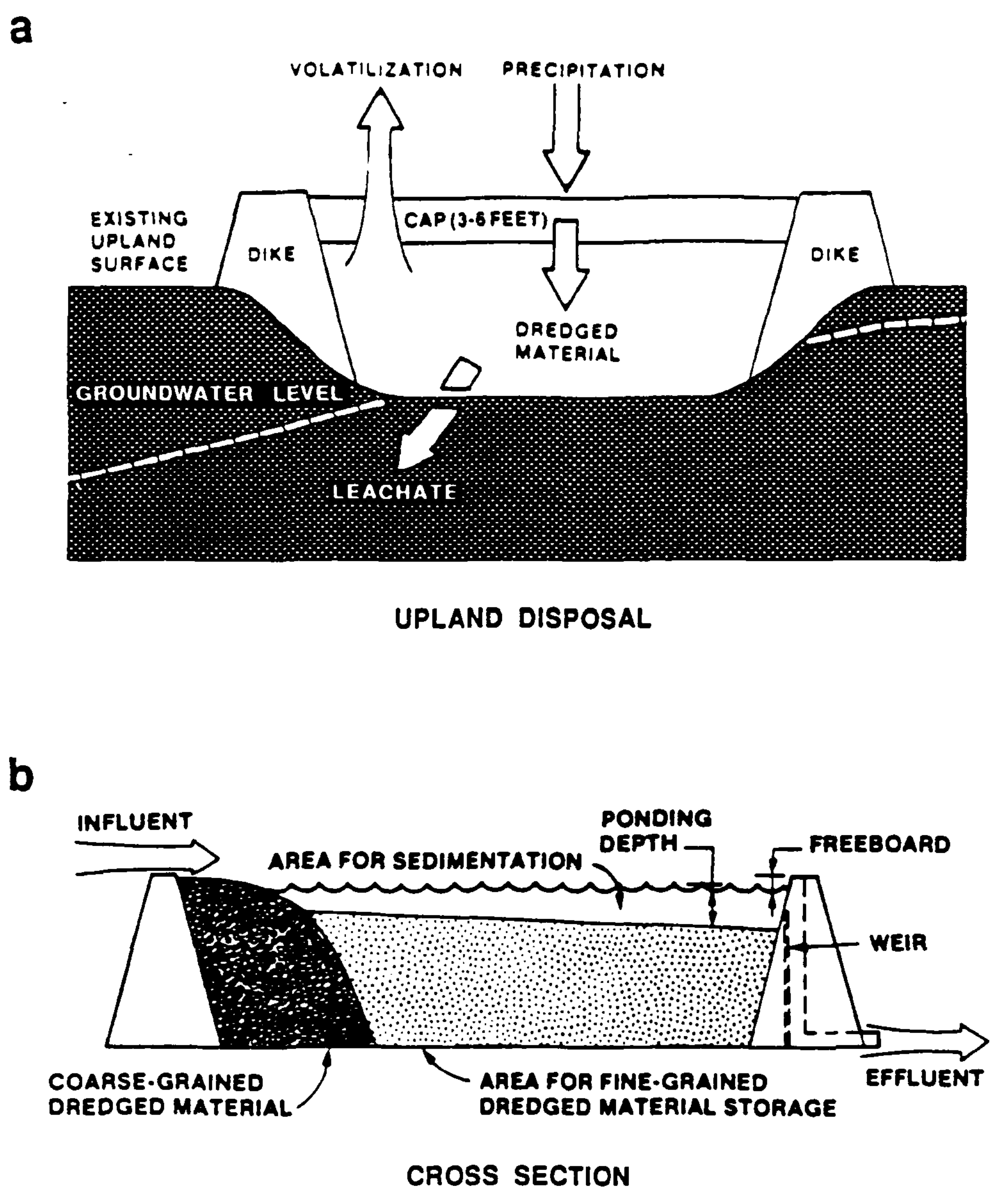
For the purpose of evaluating this alternative, it was assumed that an upland disposal site would be developed within 3 mi of the problem area. Dredging would be conducted using a pipeline cutterhead dredge and CDM would be hydraulically transported to the disposal site. Clamshell dredging can also be conducted with upland disposal as the ultimate destination, but the requirement for double handling of the CDM (i.e., removal to barge and then transfer to truck or railcar) would be a distinct disadvantage. A schematic of an upland confinement facility is presented in Figure 26. Dredge water clarification (e.g., using the secondary settling basin design shown in Figure 25) would be an essential feature of the facility. The disposal facility would be constructed to contain CDM to a depth of 15 ft. A dual synthetic liner and passive underdrainage system would be included to permit removal of percolating dredge water and allow for long-term leachate collection. The technology for utilizing an upland disposal facility is well-developed and has been applied in similar situations to wet soils, but is unproven for use with CDM.

Following sedimentation and removal of collected dredge water, passive collection of percolating water would continue until the fill had consolidated to an extent that allowed capping operations to commence. The cap would be 3 ft thick and composed of clay.

5.2.7 Removal with Hydraulic Dredge/Solidification/Upland Disposal

Solidification as an option for treatment of CDM is considered here in conjunction with hydraulic dredging and upland confinement. Solidification can significantly reduce the toxicity and mobility of problem chemicals by chemically immobilizing the metals in the solidified matrix and encapsulating the particle-associated organic compounds.

Treatment by solidification may be conducted at either nearshore or upland disposal sites. Either hydraulic or mechanical dredging equipment can



Reference: Phillips et al. (1985).

Figure 26. (a) Confined upland disposal, (b) Components of a typical diked upland disposal site.

be used for removal of the contaminated sediment. In the former case, removal of most of the dredge water by sedimentation would be required prior to blending in the solidification agents. As discussed in Section 4.0 several solidification agents and implementation scenarios are feasible for this treatment option. Solidification technologies have not been proven for use with contaminated sediments.

For the evaluation of this alternative, contaminated sediments were assumed to be hydraulically dredged and pumped to the upland site through pipelines. The advantage of this procedure is that sediment removal and discharge at the treatment site would be self-contained and continuous. Clamshell dredging could be used, but it has the disadvantage of requiring double handling of the CDM. In the confinement structure, which also serves as a sedimentation basin, dredged material would settle, and dredge water would be chemically clarified before return to the marine environment. The basin would be equipped with an underdrainage system for the further dewatering of CDM. When moisture content of the fill reached a specified value, the solidification agent would be added and blended, using mixing equipment designed for in situ solidification applications. To permit complete coverage of the confinement zone, cellular design of the disposal facility may be required, along with a mounting and track system for the mixing device. This approach to solidification of CDM has been considered, (Ludwig et al. 1985) but never implemented.

Design features for the disposal facility would depend on the hazard level of the fill. In developing this alternative, it was assumed that the treated material would be delisted as a RCRA hazardous waste and that the confinement facility could be designed to satisfy minimum technical standards. The liner would be 1 ft thick and composed of clay. An underdrainage system atop the clay liner would remove dredge water, driving the sedimentation phase of the process. The facility would accommodate a 15-ft fill depth and be capped with 1 ft of soil or clay.

5.2.8 Removal with Clamshell Dredge/Confined Aquatic Disposal

Use of a clamshell dredge for removal of sediments, followed by CAD would entail many of the same design features as appropriate for hydraulic dredging. Dredge water volume would be reduced with the clamshell, and deposition of the sediments at the CAD site would be by split-hulled barge.

For the purpose of evaluating this alternative, a deep water CAD unit is assumed. Clean capping material would be obtained by overdredging at the problem area using a watertight clamshell dredge, then transported and placed at the CAD site using a split-hulled barge. The thickness of the cap is assumed to be 3 ft.

The primary environmental impact of the remedial alternative would be destruction of the existing benthic habitat at the dredging and disposal sites. Resuspension of sediment would be a concern during both dredging and disposal operations.

5.2.9 Removal with Clamshell Dredge/Nearshore Disposal

Removal of sediments with a clamshell dredge followed by nearshore disposal would involve essentially the same design features as appropriate for hydraulic dredging and nearshore disposal. The confining dike would be constructed to allow passage of a split-hulled barge for sediment disposal. Dredge water management is not anticipated to pose any obstacles for clamshell dredging. Design and monitoring concerns for the nearshore facility are described in Section 5.2.5.

For the purpose of evaluating this alternative, a nearshore disposal facility within 5 mi of the dredging site is assumed. Other design features that were assumed for the purpose of estimating construction costs include the absence of a liner, a fill depth of 30 ft, and a cap thickness of 3 ft.

5.2.10 Removal with Clamshell Dredge/Solvent Extraction/Upland Disposal

For sediments containing primarily organic contaminants, solvent extraction followed by incineration of the organic concentrate is a feasible alternative. Depending on the concentration of metals in the problem sediments, all disposal options may be considered. This approach to sediment remediation, like incineration, results in permanent removal and destruction of organic compounds.

For the purpose of evaluating this alternative, use of the B.E.S.T.^{tm} technology marketed by Resource Conservation Company was assumed. This process takes advantage of the inverse immiscibility properties of aliphatic amines to separate organics from aqueous slurries of contaminated material and from organic sludges. Effluents from the process would include wastewater, treated solids, and a concentrated waste organic mixture. Depending on the quality of the wastewater, additional treatment may be required. Solids retain a low residual concentration of extracting solvent and, depending on metals content, may be either returned to the removal site for unconfined disposal or landfilled in a secure facility. The extracting solvent, typically triethylamine, is not a listed hazardous waste constituent (40 CFR Part 261.3), which simplifies waste solids and wastewater disposal.

It was assumed that contaminated sediments would be dredged using a clamshell, transported via barge, and off-loaded using a clamshell to an onshore treatment facility. The CDM would be treated, dried, and transported to an upland disposal facility. Because the process effectively dewaters the solids, stabilization was considered unnecessary.

5.2.11 Removal with Clamshell Dredge/Thermal Treatment/Upland Disposal

Thermal treatment permanently eliminates organic contamination in sediments. This alternative has limited application in Elliott Bay, because most problem areas are characterized by significant metals contamination.

For this alternative, sediments were assumed to be mechanically dredged. To minimize the water content of the dredged material, a watertight clamshell bucket was assumed. Wastes low in moisture content are preferred for thermal treatment because treatment costs increase significantly as the amount of water that must be driven off increases. If hydraulic dredging were selected, an additional process step to settle and recover the solids from the dredge slurry would be necessary. Even with clamshell dredging, some dewatering may prove to be cost-effective.

The dredged sediment would be transported to shore by barge and then to an upland site for incineration. It is possible that an incinerator could be located adjacent to the problem area and transport by truck could be avoided. Analysis of the incinerated residue may reveal that the material no longer requires special handling and confinement. Open-water disposal may be a feasible option for disposal of incinerated CDM, but in this alternative, disposal in a minimum security landfill was assumed for evaluation.

5.2.12 Removal with Clamshell Dredge/Biological Land Treatment/Upland Disposal

A biological treatment option using land treatment technology is considered here for the remediation of sediments contaminated with biodegradable organic compounds. Land treatment involves the incorporation of waste into the surface zone of soil, followed by management of the treatment area to optimize degradation of waste constituents by natural soil microorganisms. Chemical and physical characteristics of the waste need to be evaluated to determine the amount that can safely be loaded onto the soil without adversely impacting groundwater. Soils possess substantial cation exchange capacity, which can effectively immobilize metals. Therefore, wastes containing metals can be land-treated, but careful consideration of the assimilative capacity of the soil for metals is essential.

For evaluating this alternative, it was assumed that sediments would be removed using a clamshell to minimize water content of the dredged material. After transport by barge and truck to the land treatment facility, the sediment material would be distributed and tilled into the upper 15-30 cm of soil. The land treatment facility design would prevent stormwater runon and allow collection and management of runoff. Lysimeters and monitoring wells would be installed and periodically sampled to aid in the detection of subsurface contaminant migration.

6.0 DEVELOPMENT OF SEDIMENT REMEDIAL ACTION EVALUATION CRITERIA

A detailed analysis of the candidate sediment remedial alternatives followed by selection of the preferred alternative is the final stage of the sediment remedial evaluation process. A detailed analysis of evaluation criteria, adapted from the approach used for the Commencement Bay Feasibility Study (Tetra Tech 1988a), is presented in Appendix C. Section 6.0 presents an outline of the criteria used to analyze the alternatives and select the preferred one. A narrative evaluation matrix is included in Section 7.0 to provide a summary of the key considerations for each criterion of the candidate alternatives selected for detailed analysis.

Evaluation criteria for the detailed analysis can be grouped into three general categories: effectiveness, implementability, and cost. For the evaluation of sediment remedial alternatives in Elliott Bay, four effectiveness criteria: short-term protectiveness; timeliness; long-term protectiveness; and reduction in contaminant toxicity, mobility, or volume were evaluated. The three implementability criteria comprise technical feasibility, institutional feasibility, and availability of disposal facilities. Other types of implementability criteria, such as coordination among agencies and public acceptance, are not discussed in this document because they are nontechnical aspects of the remediation action. Cost elements include design and specification preparation, capital construction, habitat mitigation, operation and maintenance (O&M), and monitoring.

6.1 EFFECTIVENESS CRITERIA

Short-term protectiveness is the predicted ability of the candidate sediment remedial alternative to minimize public health and environmental risks caused by exposure to contaminants during the implementation phase. Considerations for short-term protectiveness include potential public exposure to contaminants during dredging, transport, treatment, and disposal, and potential failures of equipment or technologies during implementation.

Timeliness refers to the estimated time required for the candidate alternative to meet the remedial objectives. Included in the timeliness criterion is the time required for demonstrations and modeling, development of facilities, and implementation of the alternative. Source control is an integral component of sediment remedial alternatives. However, it is assumed during the evaluation of alternatives for the Elliott Bay problem areas that source control is occurring concurrently.

Long-term protectiveness is the predicted ability of the candidate sediment remedial alternative to minimize potential hazards in both the problem area and the ultimate disposal site after the objectives of the alternative have been met. This evaluation includes an assessment of long-term reliability of containment facilities, protection of public health, and protection of the environment.

Reductions in toxicity, mobility, and volume are used in assessing protection achieved through treatment technologies versus protection achieved through prevention of exposure. The degree to which treatment processes are irreversible, the type and quantity of residuals remaining following treatment, the methods for managing residuals, and the applicability of the treatment technology to the contaminants in the sediment are considered.

6.2 IMPLEMENTABILITY CRITERIA

Technical feasibility is the ability of the candidate sediment remedial alternative to be fully implemented based on site-specific chemical and physical characteristics, as well as general construction and engineering constraints. Feasibility and reliability of process options, implementation of monitoring programs, and implementation of operation and maintenance (O&M) programs are considered.

Institutional feasibility is the ability of the candidate sediment remedial alternative to meet the intent of all applicable criteria, regulations, and permitting programs. Considerations under the institutional feasibility criterion include approval of relevant agencies, and compliance with applicable or relevant and appropriate requirements (ARARs). The criterion for approval of relevant agencies addresses the need for, and feasibility of, obtaining concurrence from appropriate agencies such as U.S. EPA and Ecology on whether the candidate alternative will meet the substantive aspects of permit requirements. ARARs are divided into categories of chemical-specific, location-specific, and action-specific criteria.

Chemical-specific ARARs are health-based or risk-based concentrations or ranges of concentrations in environmental media for specific chemicals. Examples of chemical-specific ARARs are federal water quality criteria (WQC), air quality standards (federal, state, and local), and maximum contaminant levels (MCL) or MCL goals (MCLG), established by the Safe Drinking Water Act (SDWA) and RCRA. The National Institute of Occupational Safety and Health (NIOSH) sets the permissible exposure level (PEL) for hazardous substances in the workplace. The American Council of Governmental Industrial Hygienists (ACGIH) has defined a threshold level value (TLV) for exposure to hazardous substances. Selected chemical-specific ARARs are presented in Table 8.

Location-specific ARARs set restrictions or remedial activities based on the characteristics of the environment in the vicinity of the site. Selected potential location-specific ARARs are presented in Table 9.

Action-specific ARARs set restrictions based directly on the nature of the alternative. Examples of action-specific ARARs include RCRA regulations for disposal of hazardous waste. Selected potential action-specific ARARs are presented in Table 10.

The availability criterion addresses the availability of the equipment and expertise required to perform the candidate alternative, as well as the availability of the necessary treatment, storage, or disposal facility. Current stage of development and potential vs. current availability are also considered.

TABLE 8. SELECTED POTENTIAL CHEMICAL-SPECIFIC ARARs FOR PROBLEM AREA CHEMICALS

Chemical	RCRA MCL (mg/L)	SDWA MCL (mg/L)	Marine WQC Chronic (mg/L)	SDWA MCLG (mg/L)	NIOSH[a] PEL (mg/m^3)	ACGIH[a] TLV (mg/m^3)
Antimony	--	--	--	--	0.5	0.5[b]
Arsenic	0.05	--	0.013	--	0.01	0.002[c]
Cadmium	0.01	0.01	0.0093	0.005	0.1	0.05[d]
Copper	--	--	0.0029	1.3	1.0	--
Lead	0.05	0.05	0.0056	0.02	0.05	<0.1[b]
Mercury	0.002	0.002	2.5E-05	0.003	0.05[b]	0.05
Nickel	0.0134	--	0.0071	--	1	1
Zinc	--	--	0.058	--	--	--
Tetrachloroethene	--	--	--	--	35	7
Hexachlorobenzene	--	--	--	--	--	--
1,2-Dichlorobenzene	--	--	--	0.62	300[d]	--
1,3-Dichlorobenzene	--	--	--	--	--	--
1,4-Dichlorobenzene	--	0.75	--	0.75	75	--
Hexachlorobutadiene	--	--	0.032[e]	--	--	--
HPAH	--	--	--	--	--	--
LPAH	--	--	--	--	--	--
Methylphenanthrenes	--	--	--	--	--	--
Dibenzothiophene	--	--	--	--	--	--
Dibenzofuran	--	--	--	--	--	--
4-Methylphenol	--	--	--	--	--	--
Phenol	--	--	5.8	--	19	20[b]
2-Methylphenol	--	--	--	--	--	--
Naphthalene	--	--	--	--	50	--
2-Methylnaphthalene	--	--	--	--	--	--
Biphenyl	--	--	--	--	1	--
Pentachlorophenol	--	--	3.4E-04	0.221	0.5	--
Dibenzothiophene	--	--	--	--	--	--
Ethylbenzenes	--	--	0.43	0.681	--	--
Xylenes	--	--	--	--	435	100[b]
Bis(2-ethylhexyl)phthalate	--	--	--	--	--	--
Benzyl alcohol	--	--	--	--	--	--
N-nitrosodiphenylamine	--	--	--	--	--	--
Retene	--	--	--	--	--	--
Butyl benzyl phthalate	--	--	--	--	--	--
Phthalate esters	--	--	0.034	--	--	--
PCBs	--	--	3.0E-05	--	--	--

[a] 8-h time-weighted average unless otherwise indicated - units in mg/m^3 of air.

[b] 10-h time-weighted average.

[c] 15-min ceiling.

[d] Ceiling value.

[e] Lowest observed effect level.

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TABLE 9. SELECTED POTENTIAL LOCATION-SPECIFIC ARARs FOR CANDIDATE REMEDIAL ALTERNATIVES

Location	Requirement	Prerequisites	Citation	Status (A/RA)[a]
Within 100-year floodplain	Facility must be constructed, maintained, and operated to prevent washout	RCRA hazardous waste treatment, storage, and disposal	40 CFR 264.18(b)	RA
Within floodplain	Action to avoid adverse effects, minimize potential harm, restore and preserve natural and beneficial values	Action will occur in lowlands and flat areas adjoining inland and coastal waters	Executive Order 11988; 40 CFR 6 Appendix A	A
Within coastal zone	Conduct activity in manner consistent with Washington Shoreline Management Act	Activities affecting coastal zone, including shorelands, tidelands, and submerged lands	Coastal Zone Management Act (16 USC Section 1451)	A
			Washington Shoreline Management Act	A
			Seattle Shoreline Master Program	A
Oceans or waters of the United States	Action to dispose of dredged and fill material requires a permit	Oceans and waters of the United States	Clean Water Act Section 404, 401, 40 CFR 125	A
			Marine Protection Resources and Sanctuaries Act Section 103	RA
	Disposal of dredged material under permit authority of the U.S. Army Corps of Engineers		Rivers and Harbors Appropriations Act Section 10	A
Washington State waters	Action affecting the natural flow of water requires a permit		Department of Fisheries and Game Hydraulics Permit RCW 75-20.100, WAC 220-110	A
Puget Sound	Dredged material must meet chemical and biological criteria for disposal in Puget Sound	Dredged material disposal in Puget Sound	Puget Sound Dredged Disposal Analysis	RA
Seattle	Construction activities within Seattle city limits must comply with city land use and permit requirements	Construction in Seattle city limits	Seattle Land Use Plan	A

[a] A = Applicable
RA = Relevant and appropriate.

TABLE 10. SELECTED POTENTIAL ACTION-SPECIFIC ARARs
FOR CANDIDATE REMEDIAL ALTERNATIVES

Location	Requirement	Prerequisites	Citation	Status (A/RA)[a]
Upland disposal (closure) of RCRA hazardous waste	Removal of all contaminated material	RCRA hazardous waste placed at site, or movement of waste from one area to another	40 CFR 264.11, 40 CFR 264.228, and 264.258, 40 CFR 264.228(a)(-2), and 264.258(6), 40 CFR 264.310	A
			52 CFR 8712	RA
Upland disposal (containment) of RCRA hazardous waste	Construction of new landfill onsite Design, maintenance, and operation requirements	RCRA hazardous waste placed in new landfill	40 CFR 264.301, 264.303, 264.304, 264.310, 264.314, 268 Subpart D, 264.220, 264.221	A
Upland disposal (post closure)	Monitoring requirements	RCRA hazardous waste	40 CFR 246.1	A
Upland disposal of extremely hazardous waste	Designation of material as extremely hazardous	State extremely hazardous waste (EHW)	WAC 173-303-081	A
	Disposal in state-approved facility	State EHW	WAC 173-303-140	A
Upland disposal of solid waste or dangerous waste	Designation of material as not extremely hazardous waste	Material must not be classified as EHW	WAC 173-303-081	A
	Disposal in an approved surface impoundment	Material must not be classified as EHW	WAC 173-303-650	A
	Disposal in an approved surface impoundment	Material must not be classified as EHW	King County Health Department Regulations for Sanitary Landfills	A
Dredging and disposal of dredged material open water and nearshore	Dredging in waters of the United States requires a permit	Waters of the United States	Clean Water Act Section 404, 40 CFR 125	A
	Action to dispose of dredged material requires a permit			
	Dredging or aquatic disposal of dredged material requires state water quality certification		Clean Water Act Section 401, 40 CFR 125	A
	Guidelines and criteria for testing dredged material and establishing disposal sites	Oceans of the United States	Marine Protection Resources and Sanctuaries Act	RA
		Puget Sound	Puget Sound Dredged Disposal Analysis (pending)	A
	Requirement for a hydraulics permit	Interference with natural water flow of Washington state waters	RCW 75-20.100 WAC 220-110	A

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TABLE 10. (Continued)

Location	Requirement	Prerequisites	Citation	Status (A/RA)[a]
	Requirement for a shoreline substantial development permit	Disposal site within Seattle city limits	Seattle Shoreline Master Program	A
Upland disposal (groundwater protection)	Groundwater monitoring at RCRA disposal facilities	RCRA hazardous waste	40 CFR 264.90-264.-101, 265.90-265.94	A
	General protection requirements			A
Transportation of hazardous waste	Regulations for the transportation of hazardous waste on federal highways	Hazardous waste transport on federal highways	49 CFR 107, 171.1-171.500	A
	Regulations for the transportation of hazardous waste on Washington state highways	Hazardous waste transport on Washington state highways	WAC 412-195	A
Incineration of dredged material	Requirements for incineration of RCRA hazardous waste	RCRA hazardous waste	40 CFR 264.340-264.999, 265.270-265.299 PSAPCA permit issuance	
	Requirements for incinerators to achieve local standards, new source requirements			
Direct discharge of treatment system effluent	Requirements and criteria including compliance with federal WQC and BAT[b]; NPDES[c] permit requirements	Direct discharge to waters of the United States	40 CFR 125.123(b), 125.122, 125.123(d)(1), 125.124	A
Discharge to a POTW[d]	Requirements for discharges to POTWs	Discharge to Metro POTWs	40 CFR 403.5, 40 CFR 264.71, 264.72	A
	Metro Pretreatment Program		Metro POTW Pretreatment Program	A
Land treatment	Design, monitoring and treatment requirements	RCRA hazardous waste	40 CFR 264.271, 264.273, 264.276, 264.278, 264.281, 264.282, 264.283	A
Treatment	Proposed standards for treatment other than incineration and land treatment	RCRA hazardous waste	50 CFR 40726, 40 CFR 264, 40 CFR 268.10-268.13, 42 U.S.C. 3004(d)(3), 3004(e)(3), 6924(d)(3), 6924(e)(3)	A[e]

[a] A = Applicable
RA = Relevant and appropriate.
[b] Best available technology.
[c] National Pollution Discharge Elimination System.
[d] Publically owned treatment works.
[e] These are proposed standards and will probably be applicable once promulgated.

6.3 COST CRITERIA

Order-of-magnitude costs were estimated for each combination of sediment remedial alternatives for the selected problem areas. Costs were grouped into construction and implementation (initial cost), and O&M costs. Included in the initial costs are the costs associated with engineering design, development of specifications, dredging, transport, treatment, intertidal habitat replacement, and disposal. O&M costs include all post-disposal onsite activities, including monitoring, and facility upkeep and maintenance. Cost estimates for specific items within each category were normalized to 1988, using an annual inflation rate of 6 percent. For yearly costs associated with monitoring, operation, and maintenance, the present worth was calculated using a 10 percent interest rate. A discussion of the estimation methods, assumptions, and information sources used is presented in the Commencement Bay Feasibility Study, Appendix D (Tetra Tech 1988a).

7.0 SELECTION OF PREFERRED ALTERNATIVES

7.1 EVALUATION OF ALTERNATIVES FOR DENNY WAY PROBLEM AREA

The 12 sediment remedial alternatives identified in Section 5.0 broadly encompass the general approaches and technology types available for sediment remediation. In the following discussion, this set of alternatives is evaluated to determine the suitability of each for the remediation of contaminated sediments in the Denny Way and North Harbor Island problem areas. The objective of this evaluation is to identify the preferred alternative for each area based on the criteria of effectiveness, implementability, and cost.

To evaluate sediment remedial alternatives in the Denny Way problem area, the indicator chemicals mercury, fluoranthene, chrysene, butyl benzyl phthalate, bis(2-ethylhexyl)phthalate, and total PCBs were selected. Areal distributions of the indicator chemicals based on target cleanup goals are shown in Figures 6-11. The approximate areal extent of sediments which exceeded the sediment cleanup goals for organic and inorganic contaminants is presented in Figure 27. Interpolation of contaminant concentrations between sampling stations was used to define areal distribution of indicator chemicals. The concentrations of indicator chemicals were assumed to vary linearly between sampling stations. Sediments exceeding sediment cleanup goals cover an area of approximately 220,000 yd^2. Sediment core data were not available for all sampling stations, therefore, the depth of contamination was assumed to be 3 ft. The assumed depth of sediment contamination represents an approximation which pertains to costing aspects only. Sampling prior to sediment removal will be necessary to provide more precise information on contaminant depths. For remedial alternatives requiring sediment removal, a volume of 220,000 yd^3 of sediments exceeding sediment cleanup goals was used for costing.

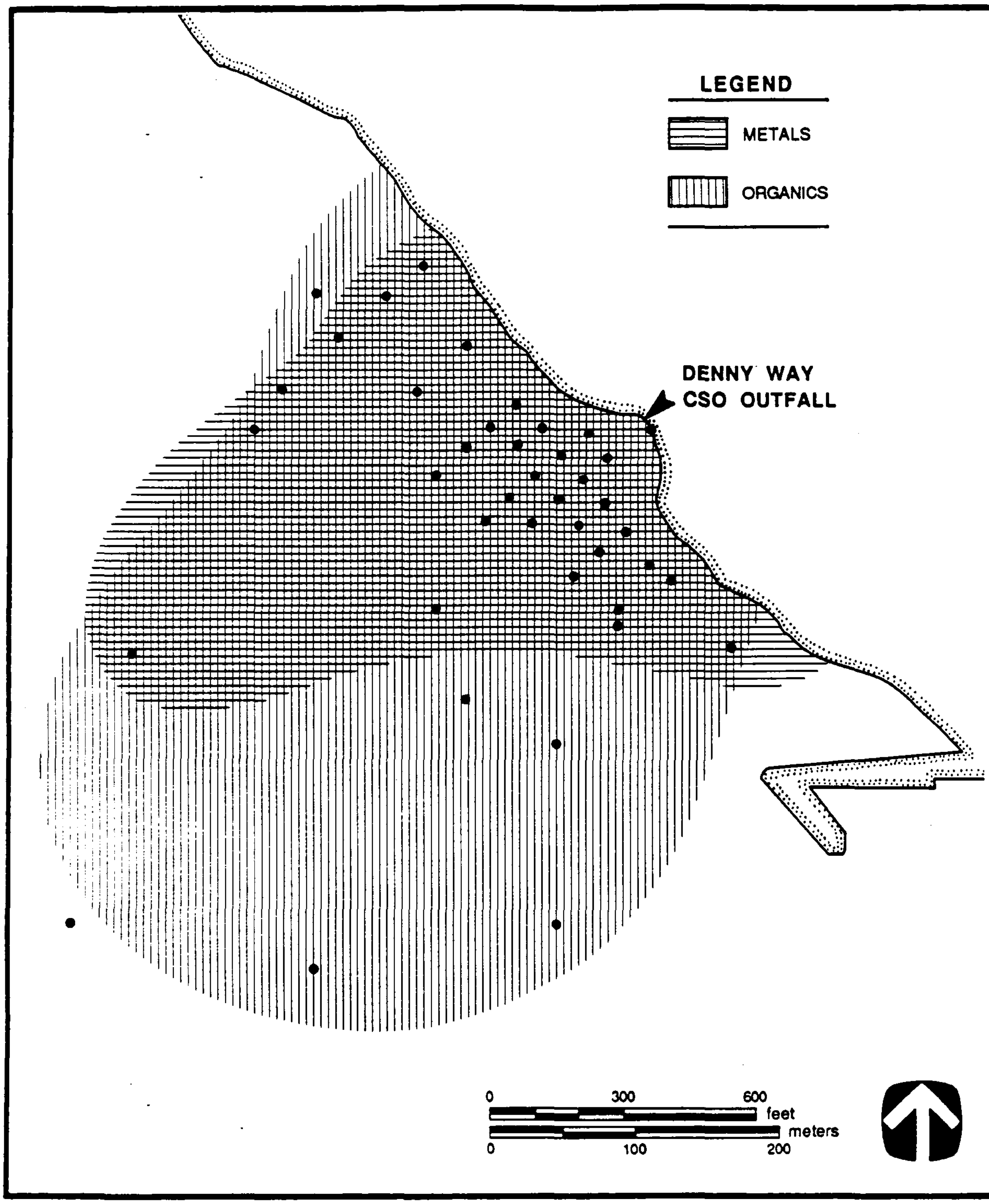

Figure 27. Approximate areal extent of sediments exceeding sediment cleanup goals at Denny Way problem area.

Sediments with contaminant concentrations exceeding sediment cleanup goals are found at depths ranging from intertidal to approximately 150 ft. Dredging is possible to depths of approximately 100 ft with a clamshell dredge and 50 ft using a large hydraulic dredge. If dredging below 100 ft is necessary, the use of a specialty dredge such as the pneuma pump would be required. For sediments in water depths below 100 ft with concentrations of contaminants exceeding sediment cleanup goals, in situ capping is also possible. Candidate alternatives which involve hydraulic dredging as a component technology are not considered for further evaluation because depths in the Denny Way problem area extend beyond 50 ft. The substitution of clamshell dredging for hydraulic dredging as the sediment removal technology is feasible for all alternatives. The need for dredge water management and dewatering considerations associated with hydraulic dredging are reduced for clamshell dredging when compared with hydraulic dredging. Additional dredged material handling for candidate alternatives involving upland disposal of treated or untreated sediments is required.

The presence of both organic and inorganic contaminants in concentrations exceeding sediment cleanup goals at the site (Table 2) dictate that a treatment process for organics and inorganics is appropriate, if sediment removal and treatment are component technologies of the remedial alternative. Total metals concentrations will limit the applicability of solvent extraction, thermal treatment, and land treatment, therefore, the alternatives incorporating these treatment processes are not evaluated for the Denny Way problem area. Solidification technologies may be successful, however, the concentrations of organic contaminants may limit applicability.

Eight of twelve sediment remedial alternatives are evaluated below for the cleanup of the Denny Way problem area:

- No action

- Institutional controls

- In situ capping

- Clamshell dredging/nearshore disposal

- Clamshell dredging/upland disposal

- Clamshell dredging/solidification/upland disposal

- Clamshell dredging/confined aquatic disposal

- Clamshell dredging/solvent extraction/upland disposal.

The primary evaluation criteria are effectiveness, implementability, and cost. A narrative matrix assessing each alternative is presented in Table 11. A comparative evaluation of alternatives based on ratings of high, moderate, and low in the various subcategories of evaluation criteria is presented in Table 12. The subcategories of evaluation criteria are short-term protectiveness; timeliness; long-term protectiveness; reduction in toxicity, mobility, or volume; technical feasibility; institutional feasibility; availability; capital costs; and O&M costs. Remedial costs were developed for sediments currently exceeding sediment cleanup goals.

7.1.1 Short-Term Protectiveness

The comparative evaluation for short-term protectiveness resulted in low ratings for no action and institutional controls, because adverse impacts would continue with the sediments remaining in place. Source control measures initiated as part of the institutional controls would decrease inputs of contaminants, but adverse impacts would persist in the short-term.

All alternatives involving dredging received moderate ratings primarily because of the resuspension of contaminated sediment during removal. The clamshell dredging/CAD alternative would also result in sediment resuspension at the disposal site. All dredging alternatives would result in the loss of benthic habitat in the Denny Way problem area over the short-term. The CAD alternatives could also result in the loss of benthic habitat at the disposal site. Selection of an appropriate CAD site in a separate contaminated area could result in the mitigation of the additional area following

TABLE 11. REMEDIAL ALTERNATIVES EVALUATION MATRIX FOR THE DENNY WAY PROBLEM AREA

			NO ACTION	INSTITUTIONAL CONTROLS	IN SITU CAPPING	CLAMSHELL DREDGE/ NEARSHORE DISPOSAL	CLAMSHELL DREDGE/ UPLAND DISPOSAL	CLAMSHELL DREDGE/ SOLIDIFICATION/ UPLAND DISPOSAL	CLAMSHELL DREDGE/ CONFINED AQUATIC DISPOSAL	CLAMSHELL DREDGE/ SOLVENT EXTRACTION/ UPLAND DISPOSAL
EFFECTIVENESS	SHORT-TERM PROTECTIVENESS	COMMUNITY PROTECTION DURING IMPLEMENTATION	NA	There are no elements of institutional control measures that have the potential to cause harm during implementation.	Community exposure is not a concern in the implementation of this alternative. CDM exposure and handling are minimal.	Public access to dredge and disposal sites is restricted. Public exposure potential is low.	Public access to dredge and disposal sites is restricted. Exposure from CDM spills or mishandling is possible, but overall potential is low.	Public access to dredge, treatment, and disposal sites is restricted. Exposure from CDM spills or mishandling is possible, but overall potential is low. Extended duration of operation may result in moderate exposure potential.	Public access to dredge and disposal sites is restricted. Community exposure is negligible.	Public access to dredge, treatment, and disposal sites is restricted. Extended duration of treatment operations may result in moderate exposure potential.
		WORKER PROTECTION DURING IMPLEMENTATION	NA	There are no elements of institutional control measures that have the potential to cause harm during implementation.	Workers are not exposed to contaminated sediments.	Operational controls can be implemented during dredging and transport to minimize potential for worker exposure. Workers wear protective gear.	Operational controls can be implemented during dredging and transport to minimize potential for worker exposure. Workers wear protective gear. Additional CDM handling associated with dewatering and transport increases worker risk over aquatic or nearshore disposal.	Operational controls can be implemented during dredging and transport to minimize potential for worker exposure. Workers wear protective gear. Additional CDM handling associated with treatment increases worker risk over dredge/disposal options.	Operational controls can be implemented during dredging and transport to minimize potential for worker exposure. Workers wear protective gear.	Additional CDM handling associated with treatment increases worker risk over dredge/disposal options. Workers wear protective gear.
		ENVIRONMENTAL PROTECTION DURING IMPLEMENTATION	Original contamination remains. Source inputs continue. Adverse biological impacts continue.	Source control is implemented. Contaminants remain and adverse biological impacts continue at existing levels.	Existing contaminated habitat is destroyed and replaced with clean material.	Existing contaminated habitat is destroyed. Nearshore disposal habitat is lost. Contaminated sediment is resuspended.	Existing contaminated habitat is destroyed. Contaminated sediment is resuspended during dredging operations.	Existing contaminated habitat is destroyed. Contaminated sediment is resuspended during dredging operations.	Existing contaminated habitat and disposal site habitat are destroyed. Contaminated sediment is resuspended during dredging and disposal operations. Dredge water management is improved over hydraulic dredging.	Existing contaminated habitat is destroyed. Contaminated sediment is resuspended during dredging operations.
	TIMELINESS	TIMELINESS	The no action alternative is in force in the absence of any other action. Sediments are unlikely to recover in the absence of source control.	Access restrictions and monitoring efforts can be implemented quickly. Source controls can be implemented within 1 to 2 years. Partial sediment recovery is achieved naturally, but significant contaminant levels persist.	In situ capping can be implemented within approximately 1 to 2 years.	Dredge and disposal operations could be accomplished within approximately 2 years. Disposal siting and facility construction delay implementation.	Dredge and disposal operations could be accomplished within approximately 2 years. Disposal siting and facility construction delay implementation.	Bench and pilot scale testing are required. Full scale equipment is available. Remediation could be accomplished within 1 to 2 years.	CAD can be accomplished within approximately 1 to 2 years.	Bench and pilot scale testing are required. Full scale equipment is available. Remediation could be accomplished within 1 to 2 years.
	LONG-TERM PROTECTIVENESS	LONG-TERM RELIABILITY OF CONTAINMENT FACILITY	CDM containment is not an aspect of this alternative.	CDM containment is not an aspect of this alternative.	The long-term reliability of the cap to prevent contaminant re-exposure in the absence of physical disruption is considered acceptable.	Nearshore confinement facilities structurally reliable. Dike and cap repairs can be readily accomplished.	Upland confinement facilities may be considered structurally reliable. Dike and cap repairs can be readily accomplished. Underdrain or liner cannot be repaired.	Upland confinement facilities may be considered structurally reliable. Treated CDM may be suitable for use as inert construction material or disposal at a standard solid waste landfill.	The long-term reliability of the cap to prevent contaminant re-exposure in the absence of physical disruption is considered acceptable.	Treated CDM low in metals can be used as inert construction material or disposed of at a standard solid waste landfill.
		PROTECTION OF PUBLIC HEALTH	The potential for exposure to harmful sediment contaminants via ingestion of contaminated food species remains.	The potential for exposure to harmful sediment contaminants via ingestion of contaminated food species remains, albeit at a reduced level as a result of consumer warnings and source controls.	The confinement system precludes public exposure to contaminants by isolating contaminated sediments from the overlying biota. Protection is adequate.	The confinement system precludes public exposure to contaminants by isolating CDM. Variable physicochemical conditions in the fill increase potential for contaminant migration over CAD.	The confinement system precludes public exposure to contaminants by isolating CDM. The potential for groundwater contamination is low. Upland disposal facilities are more secure than nearshore facilities.	Harmful contaminants are bound in the treated CDM. The potential for groundwater contamination is low. Permanent treatment for contaminants is not effected.	The confinement system precludes public exposure to contaminants by isolating contaminated sediments from the overlying biota. Protection is adequate.	Harmful organic contaminants are removed from CDM. Concentrated contaminants are disposed of by RCRA- approved treatment or disposal. Permanent treatment for organic contaminants is effected.
		PROTECTION OF ENVIRONMENT	Original contamination remains. Source inputs continue. Exposure potential remains at existing levels or increases.	Original contamination remains. Source inputs are controlled. Adverse biological effects continue but decline slowly as a result of sediment recovery and source control.	The confinement system precludes environmental exposure to contaminated sediment. Thickness of overlying cap prevents exposure of burrowing organisms. Potential for contaminant migration is low because CDM is maintained at in situ conditions.	The confinement system precludes environmental exposure to contaminated sediment. The potential for contaminant migration into marine environment is increased over CAD.	Upland disposal is secure, with negligible potential for environmental impact if properly designed. Potential for shallow groundwater contamination exists.	Upland disposal is secure, contaminant monitoring is improved over nearshore. Potential for shallow groundwater contamination exists.	The confinement system precludes environmental exposure to contaminated sediment. Thickness of overlying cap prevents exposure of burrowing organisms. Potential for contaminant migration is low because CDM is maintained at in situ conditions.	Harmful organic contaminants are removed from CDM. Concentrated contaminants are disposed of by RCRA- approved treatment or disposal. Residual contamination is reduced below harmful levels.
	CONTAMINANT MIGRATION	REDUCTION IN TOXICITY, MOBILITY, AND VOLUME	Sediment toxicity and contaminant mobility are expected to remain at current levels or increase as a result of continued source inputs. Contaminated sediment volume increases as a result of continued source inputs.	Sediment toxicity is expected to decline slowly with time as a result of source input reductions and sediment recovery. Contaminant mobility is unaffected. Volume of contaminated sediment remains at preremediation level or declines.	The toxicity of contaminated sediments in the confinement zone remains at preremediation levels. Mobility of contaminants remains at preremediation level. Volume of contaminated sediments is unaffected.	The toxicity of CDM in the confinement zone remains at preremediation levels. Altered conditions resulting from dredge/disposal operations may increase mobility of metals. Volume of contaminated sediments is not reduced.	The toxicity of CDM in the confinement zone remains at preremediation levels. The potential for migration of metals is greater for upland disposal than for CAD or nearshore disposal. Volume of contaminated sediments is not reduced.	The toxicity of treated CDM is not reduced. Mobility of contaminants is reduced. Volume of CDM for disposal increases.	The toxicity and mobility of contaminated sediments in the confinement zone remains at preremediation levels. Volume of CDM is not reduced.	Harmful contaminants are removed from CDM. Concentrated contaminants are disposed of by RCRA- approved treatment or disposal. Toxicity and mobility considerations are eliminated. Volume of contaminated material is substantially reduced.

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TABLE 11. (CONTINUED).

			NO ACTION	INSTITUTIONAL CONTROLS	IN SITU CAPPING	CLAMSHELL DREDGE/ NEARSHORE DISPOSAL	CLAMSHELL DREDGE/ UPLAND DISPOSAL	CLAMSHELL DREDGE/ SOLIDIFICATION/ UPLAND DISPOSAL	CLAMSHELL DREDGE/ CONFINED AQUATIC DISPOSAL	CLAMSHELL DREDGE/ SOLVENT EXTRACTION/ UPLAND DISPOSAL
IMPLEMENTABILITY	TECHNICAL FEASIBILITY	FEASIBILITY AND RELIABILITY OF REMEDIAL ACTION PROCESS OPTIONS	Implementation of this alternative is feasible and reliable.	Source control and institutional control measures are feasible and reliable. Source control reliability assumes all sources can be identified.	Clamshell dredges and split-hulled barges are conventional and reliable equipment. In situ capping is a demonstrated technology.	Clamshell dredges and split-hulled barges are conventional and reliable equipment. Nearshore confinement of CDM has been successfully accomplished.	Clamshell dredges and split-hulled barges are conventional and reliable equipment. Secure upland confinement technology is well developed.	Clamshell dredges and split-hulled barges are conventional and reliable equipment. Solidification process would require bench and pilot scale testing to determine reliability and feasibility of large scale process.	Clamshell dredges and split-hulled barges are conventional and reliable equipment. CAD of contaminated sediments is feasible and reliable. CAD is a demonstrated containment technology.	Sludges, soils, and sediments have successfully been treated using this technology.
		IMPLEMENTATION OF MONITORING PROGRAMS	No monitoring over and above programs established under other authorities are implemented.	Sediment monitoring schemes can be readily implemented. Adequate coverage of problem area would require an extensive program.	Confinement reduces monitoring requirements in comparison to institutional controls. Sediment monitoring schemes can be readily implemented.	Monitoring can be readily implemented to detect contaminant migration through dikes. Improved confinement enhances monitoring compared with CAD.	Monitoring can be readily implemented to detect contaminant migration through dikes. Improved confinement enhances monitoring over CAD. Installation of monitoring systems is routine aspect of facility siting.	Monitoring can be readily implemented to detect contaminant migration.	Confinement reduces monitoring requirements in comparison to institutional controls. Sediment monitoring schemes can be readily implemented.	Monitoring is required only to evaluate the reestablishment of benthic communities. Monitoring programs can be readily implemented.
		IMPLEMENTATION OF OPERATING AND MAINTENANCE PROGRAMS	There are no O & M requirements associated with the no action alternative.	O & M requirements are minimal. Some O & M is associated with monitoring, maintenance of warning signs, and issuance of ongoing health advisories.	O & M requirements are minimal. Some O & M associated with monitoring.	O & M requirements consist of inspections, groundskeeping, and maintenance of monitoring equipment.	O & M requirements consist of inspections, groundskeeping, and maintenance of monitoring equipment.	O & M costs are minimal at the conclusion of CDM treatment. System maintenance is intensive during implementation.	O & M requirements are minimal. Some O & M associated with monitoring.	No O & M costs are incurred at the conclusion of CDM treatment. System maintenance is intensive during implementation.
	INSTITUTIONAL FEASIBILTY	APPROVAL OF RELEVANT AGENCIES	Approval is denied as a result of agency commitments to mitigate observed biological effects.	Requirements for agency approvals are minimal and are expected to be readily obtainable.	Approvals from the City of Seattle, COE, EPA, and state agencies are feasible.	Approvals from the City of Seattle, COE, EPA, and state agencies are feasible. Availability of approvals for facility siting are uncertain but are assumed feasible. However, disposal of untreated CDM is considered less desirable than if CDM is treated.	Approvals from the City of Seattle, COE, EPA, and state agencies are feasible. Coordination is required for establishing discharge criteria for dredge water maintenance. However, disposal of untreated CDM is considered less desirable than if CDM is treated.	Approvals depend largely on result of pilot testing and nature of the material following treatment.	Approvals from the City of Seattle, COE, EPA, and state agencies are feasible. However, disposal of untreated CDM is considered less desirable than if CDM is treated.	Approvals depend largely on results of pilot testing and the nature of treatment residuals.
		COMPLIANCE WITH CHEMICAL- AND LOCATION-SPECIFIC ARARS AND GUIDELINES	AET levels in sediments are exceeded. No permit requirements exist. This alternative fails to meet the intent of NCP because of ongoing impacts.	AET levels in sediments are exceeded. This alternative fails to meet intent of NCP because of ongoing impacts. State requirements for source control are achieved. Coordination with Seattle-King County Health Department for health advisories for seafood consumption.	WISHA/OSHA worker protection is required. Section 401 and 404 permits, hydraulics permit, and Shoreline Management permit are required.	WISHA/OSHA worker protection required. Sections 401 and 404, hydraulics, and Shoreline Management permits are required. Shoreline development permit required for disposal siting.	WISHA/OSHA worker protection required. Sections 401 and 404, hydraulics, and Shoreline Management permits are required.	WISHA/OSHA worker protection required. Sections 401 and 404, hydraulics, and Shoreline Management permits are required. Requires approval from Seattle-King County Health Department for disposal.	WISHA/OSHA worker protection required. Sections 401 and 404, hydraulics, and Shoreline Management permits are required.	WISHA/OSHA worker protection required. Section 404 permit is required. Alternative complies with EPA policy for permanent reduction in contaminant mobility. Requires RCRA permit for disposal of concentrated organic waste.
	AVAILABILITY	AVAILABILITY OF SITES, EQUIPMENT, AND METHODS	All materials and procedures are available.	All materials and procedures are available to implement institutional controls.	Equipment and methods to implement this alternative are readily available.	Equipment and methods to implement alternative are readily available. Potential nearshore disposal sites have been identified but none are currently available.	Equipment and methods to implement alternative are readily available. Potential upland disposal sites have not been identified for disposal of untreated CDM.	Equipment and methods to implement alternative are readily available. Upland disposal sites are potentially available.	Equipment and methods to implement alternative are readily available. Open water CAD sites are potentially available.	Process equipment available. Disposal site availability is not a primary concern because of reduction in hazardous nature of material.

TABLE 12. EVALUATION SUMMARY FOR DENNY WAY PROBLEM AREA

	No action	Institutional Controls	In Situ Capping	Clamshell/ Nearshore Disposal	Clamshell/ Upland Disposal	Clamshell/ Solidification/ Upland Disposal	Clamshell/ CAD	Clamshell/ Solvent Extraction/ Upland Disposal
Short-Term Protectiveness	Low	Low	High	Moderate	Moderate	Moderate	Moderate	Moderate
Timeliness	Low	Low	High	Moderate	Moderate	Moderate	High	Moderate
Long-Term Protectiveness	Low	Low	High	Moderate	Moderate	High	High	High
Reduction in Toxicity, Mobility, or Volume	Low	Low	Low	Low	Low	Moderate	Low	High
Technical Feasibility	High	High	High	Moderate	Moderate	Moderate	Moderate	Moderate
Institutional Feasibility	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Availability	High	High	High	Low	Low	Moderate	Low	Moderate
Estimated Cost								
Initial	---	30,000	1,500,000	2,700,000	7,900,000	13,000,000	900,000	44,000,000
O & M	---	460,000	2,200,000	300,000	500,000	400,000	2,100,000	400,000
Total	---	490,000	3,700,000	3,000,000	8,400,000	13,400,000	3,000,000	44,000,000

capping with clean material. The clamshell dredging/nearshore disposal alternative would result in the loss of nearshore habitat over the short-term. Upland disposal involves increased handling of dredge material when compared with nearshore and confined aquatic disposal options. Alternatives involving solidification and solvent extraction technologies would require additional dredge material handling and longer implementation periods, increasing the exposure potential for workers and the community.

The in situ capping alternative rated high for short-term protectiveness. Contaminant redistribution and the potential for public or worker exposure is minimized because the sediments are left in place.

7.1.2 Timeliness

The no action and institutional control alternatives received low ratings for timeliness. With no action, sediments remain unacceptably contaminated, source inputs continue, and natural recovery is unlikely. Source inputs are controlled under the institutional controls alternative, but as discussed in Section 3.1.4, sediment recovery based on the indicator chemicals is estimated to be improbable within a reasonable timeframe for Denny Way problem area sediments.

Moderate ratings were assigned to the two alternatives involving treatment technologies and the alternatives involving nearshore and upland disposal facilities. Approval and construction of an upland or nearshore disposal facility is estimated to require 1-2 yr. Equipment and methods required for construction are already developed. Pre-implementation testing would not be extensive, and overdesign of the facility would further decrease testing requirements. The solvent extraction and solidification alternatives would require extensive testing before being accepted. Siting and construction of a treatment facility, and pilot testing are estimated to require 1-2 yr. Once approval is obtained, treatment of contaminated sediments could be accomplished within approximately 2 yr, assuming treatment rates of 500 yd^3/day.

The in situ capping and clamshell dredging/CAD alternatives were rated high for timeliness. Pre-implementation testing and modeling may be necessary to evaluate the potential for contaminant releases during dredging and contaminant migration through the cap. Such testing is estimated to require 6 mo.. Following approval of a disposal site, related testing, and modeling, the CAD alternative could be accomplished within approximately 6 mo. Disposal siting issues are less likely to delay implementation of the CAD alternative for Denny Way problem area sediments than for alternatives involving nearshore or upland disposal. The in situ capping alternative could feasibly be accomplished within approximately 6 mo after obtaining approval.

7.1.3 Long-Term Protectiveness

The evaluation for long-term protectiveness resulted in low ratings for the no action and institutional controls alternatives because the timeframe for sediment recovery is long. Following the implementation of source controls for the institutional controls alternative, contaminated sediments and bioaccumulation of toxic contaminants, environment would remain. Adverse biological impacts, such as decreased benthic abundance and bioaccumulation of toxic contaminants, would continue even though sediment contamination levels would be expected to decline.

Moderate ratings were assigned to the clamshell dredging/nearshore disposal and clamshell dredging/upland disposal alternatives for the Denny Way problem area primarily because of the increased potential for contaminant migration associated with disposal. Physicochemical changes, primarily redox reactions, that would occur when dredged material is placed in these disposal facilities would tend to increase the potential for contaminant migration. Dredge material testing and modeling would provide additional information of potential contaminant migration. The dynamics of the nearshore environment require consideration of long-term maintenance and design of a structurally reliable facility. An upland disposal facility with additional engineering controls can be considered secure; however, the security of the facility is offset by the potential for groundwater contamination.

The solidification and solvent extraction alternatives both received a high rating for long-term protectiveness. Immobilization of the contaminants via solidification or removal of contaminants via solvent extraction render the dredge material nonhazardous, assuming the treatment technologies are effective.

The in situ capping and clamshell dredging/CAD alternatives were rated high for remediation of Denny Way problem area sediments under the long-term protectiveness criterion. Maintaining or disposing of dredged material at in situ conditions reduces the potential for contaminant migration compared with nearshore or upland disposal. Isolation of the material in the subaquatic environment also provides a high degree of protection, with limited potential for exposure of contaminated sediments to the community or the environment.

7.1.4 Reduction in Toxicity, Mobility, or Volume

Low ratings were assigned to all alternatives under this criterion, except those involving treatment. Although capping, confined aquatic disposal, upland, and nearshore disposal alternatives isolate contaminated sediments from the surrounding environment, the chemistry and toxicity of the material itself would remain largely unaltered. For nearshore and upland disposal alternatives, the mobilization potential for untreated dredged material may actually increase with changes in redox conditions. Without treatment, the toxicity of contaminated sediments would remain at preremediation levels. Contaminated sediment volumes would not be reduced.

The solidification alternative received a moderate rating for this criterion, because the contaminants would be immobilized but not rendered non-hazardous. The potential for leaching over long periods of time would remain, although at lower levels than for untreated sediments. The addition of the solidification agent would also probably increase the volume of dredged material requiring disposal.

The solvent extraction alternative received a high rating for this criterion because it would effectively remove organic contaminants and render inorganic contaminants environmentally unavailable through reaction with sediment residuals. The solvent extraction process would also concentrate the remaining toxic substances into a smaller volume for disposal. Results of bench scale testing of residuals would provide sufficient data to substantiate sediment detoxification.

7.1.5 Technical Feasibility

The no action, institutional controls, and in situ capping alternatives received a high rating for technical feasibility. In situ capping received a high rating for technical feasibility because the equipment, technologies and expertise required for implementation are readily accessible. The technologies have been demonstrated to be reliable and effective elsewhere for similar operations. The no action alternative does not involve technical considerations, and the institutional controls alternative involves only minimal technical considerations.

Alternatives involving treatment received moderate ratings for the technical feasibility criterion because the treatment processes would require bench- and pilot-scale testing. The application of solidification and solvent extraction procedures to the particular mixture of organic and inorganic contaminants measured in Denny Way offshore sediments would require a demonstration of process suitability. Although both processes are believed to be suitable for application to contaminated dredge material, caution when selecting a treatment technology is warranted.

The alternatives involving clamshell dredging and nearshore, upland, or confined aquatic disposal received moderate ratings under the technical feasibility criterion. If removal of contaminated sediments from depths below approximately 100 ft is rejected from consideration, the technical feasibility of the alternatives would increase.

Environmental monitoring is an integral component of the technical feasibility criterion. Monitoring techniques are well-established and technologically feasible for all alternatives. Similar techniques would be applied to all alternatives, although the alternatives will have different sampling requirements depending on the disposal option. Monitoring is considered in the evaluation process, but is not weighted heavily in the ratings because monitoring requirements are not expected to influence the feasibility of the different alternatives.

7.1.6 Institutional Feasibility

The no action and institutional controls alternatives were assigned low ratings for institutional feasibility. Long-term protection of public health and the environment are not accomplished through implementation of either alternative at the Denny Way problem area. Neither of these alternatives would comply with the mandate of the Puget Sound Water Quality Authority for improving the quality of Puget Sound.

Moderate ratings were assigned to the remaining alternatives for several reasons. Potential difficulties may arise in obtaining approval for treatment and disposal sites, and for implementing treatment technologies. Significant uncertainty remains regarding potential aquatic, nearshore and upland disposal site availability. The development and construction of an upland or nearshore disposal site that would be suitable for contaminated dredge material would pose complex legal and bureaucratic concerns.

7.1.7 Availability

The no action, institutional controls, and in situ capping alternatives were rated high under the availability criterion because they can be readily implemented. Because of the nature of the no action and institutional controls alternatives, equipment and disposal site availability are not obstacles to implementation. Equipment and expertise are readily available for the in situ capping alternative. Disposal site availability is not a consideration because the Denny Way problem area will become both the treatment and the disposal site.

Sediment remedial alternatives that involve disposal of untreated contaminated dredge material at a nearshore, upland or confined aquatic disposal site were rated low under the availability criterion. Candidate alternatives were developed under the assumption that nearshore, upland, and confined aquatic disposal sites will be available. However, no sites are currently approved for use and no approved sites are currently under construction. Equipment and expertise for the implementation of the clamshell dredging/CAD, clamshell dredging/nearshore disposal, and clamshell dredging/upland disposal are readily available.

The remedial alternatives involving solidification and solvent extraction with upland disposal of the treated sediments were rated moderate under the availability criterion. Equipment availability is not expected to be an obstacle. However, the treatment facility will require construction and testing. Assuming treatment technologies are successful, disposal at an upland facility would be feasible.

7.1.8 Cost

Order-of-magnitude costs were estimated for each combination of remedial alternative and problem area. Costs were grouped into the following categories:

- Construction and implementation (initial) - Costs for engineering design, development of specifications, dredging, transportation, treatment, intertidal habitat replacement, and disposal.

- Operation and maintenance - O&M costs associated with all post-disposal onsite activities, including monitoring. Engineering site inspections of containment structures, erosion control, drainage, repairs, and landscape upkeep are all aspects of O&M. The latter category includes fertilization, mowing, and general maintenance of site vegetation.

Monitoring activities are designed for both short- and long-term surveillance of containment structure or cap performance. In practice, activities should begin just prior to the disposal operation and remain intense for the first year, tapering off over the course of an assumed 30-yr program. In this manner, failure to initially contain sediment contaminants can be detected immediately. In addition, frequent monitoring after completion of the remedial action allows an assessment of the rate and extent of contaminant migration that can be expected to occur over the long term. Assuming that initial monitoring efforts confirm predicted rates of contaminant migration based on preimplementation bench-scale tests and modeling studies, it is reasonable to assume that the sampling frequency can be reduced over time. The lack of contaminant releases within approximately 1 yr of sediment disposal indicates that the level of monitoring can be reduced.

Cost estimates for specific items within each category were normalized to 1988, using an annual inflation rate of 6 percent. For yearly costs associated with monitoring, operation, and maintenance, the present worth was calculated using a 10 percent interest rate. A discussion of the estimation method, assumptions, and information sources used is presented in Appendix D of Tetra Tech (1988a).

Candidate sediment remedial alternative initial and O&M costs for the Denny Way problem area are presented in Table 12. A complete breakdown for each candidate alternative and examples of remedial costs for selected Commencement Bay Feasibility Study alternatives are presented in Appendix D (Tetra Tech 1988a). The alternatives selected for the Commencement Bay Feasibility Study (Tetra Tech 1988a) are intended to provide an example for different alternatives possibly suitable to Elliott Bay (i.e., clamshell dredge/thermal treatment/upland disposal). The alternatives evaluated for the Denny Way problem area are presented in order from lowest to highest initial cost.

Initial costs for the institutional controls alternative are minimal. The O&M costs for this alternative are similar to alternatives involving nearshore and upland disposal, primarily because environmental monitoring of the relatively large problem area is more difficult than an upland or nearshore disposal site. Initial costs for the clamshell dredge/confined aquatic disposal alternative are lower than the in situ capping alternative, only because the cap thickness for in situ capping is assumed to be 6 ft thick versus a 3-ft cap thickness for a confined aquatic disposal site. If a 3-ft cap is determined to be adequate, initial costs of the in situ capping and confined aquatic disposal would be approximately equal. The O&M costs for the in situ capping and clamshell dredge confined aquatic disposal alternatives are nearly equal, with the differential arising from the site maintenance costs. The confined aquatic disposal site may be designed to cut monitoring costs through confinement in a smaller area, but for costing purposes, the area requiring monitoring is assumed to be equal for the in situ capping and confined aquatic disposal alternatives.

Initial costs for the clamshell dredging/nearshore disposal alternative are roughly double the initial costs of the in situ capping alternative. Design and construction of a nearshore disposal, including mitigation for destruction of intertidal habitat at the disposal site, accounts for the majority of the initial cost differential between the two alternatives. The O&M costs for the nearshore facility are the lowest of any alternative. The low unit cost for site maintenance and the consolidation of dredge material into a relatively small area for disposal (assuming a 30-ft fill depth) requires minimal monitoring and maintenance costs.

The initial costs for the clamshell dredge/upland disposal alternative are roughly double the initial costs of the clamshell dredge/nearshore disposal alternative. Requirements for upland disposal of CDM to provide adequate levels of protectiveness, yield relatively high initial costs for disposal facility construction. Operation and maintenance costs for an upland facility are similar to all other alternatives, except in situ capping and confined aquatic disposal.

The candidate alternatives involving solidification or solvent extraction technologies both have high initial costs. Operation and maintenance costs for the alternatives involving treatment technologies are similar to the costs for untreated sediment disposal at an upland facility, with the cost differential arising from reduced analytical costs for treated sediments.

7.2 PREFERRED ALTERNATIVE FOR DENNY WAY PROBLEM AREA

The evaluation of candidate sediment remedial alternatives for the Denny Way problem area resulted in the selection of in situ capping as the preferred alternative. The total estimated cost of the alternative is roughly equal to the costs of the clamshell dredge/confined aquatic disposal alternative. The in situ capping alternative rated high for short-term and long-term protectiveness, timeliness, technical feasibility, and availability. The technical feasibility of removing sediments from depths below 100 ft and the lack of a designated disposal for contaminated sediments were also key components of the evaluation process.

Alternatives that involve dredging and subsequent upland disposal of treated or untreated sediments received lower ratings for the majority of effectiveness and implementability criteria. The increased costs for the upland disposal alternatives and liability issues associated with disposal of contaminated dredge material at an upland site decrease the ratings for these alternatives. The decrease in mobility, toxicity, and volume associated with treatment of contaminated dredge material are not considered to be a cost effective solution to remediation of problem areas.

Metro is presently proposing to cap sediments offshore of the Denny Way CSO with clean material obtained from the Duwamish River head of navigation. The proposed capping project will be performed in cooperation with the Army Corps of Engineers during the next Duwamish River maintenance dredging scheduled for February 1989 (Romberg and Sumeri 1988). The proposed capping project will enclose an area approximately 600 ft long (longshore direction) and 200 ft wide (offshore direction). Clean dredged sediment will be placed over the proposed capping area using a method similar to that employed in the lower Duwamish capping project (Romberg and Sumeri 1988). The proposed capping area (120,000 ft^2) will not cover the entire areal extent of contaminated sediments in the Denny Way problem area identified in this document (220,000 yd^2). However, the remedial area proposed by Metro includes the most highly contaminated sediments in the vicinity of the CSO outfall. Although it is preferable to control all contaminant sources prior to sediment remediation, Metro intends to use the clean capped area as a monitoring tool to aid in identification and subsequent elimination of remaining contaminant sources in the Denny Way CSO drainage basin (Romberg and Sumeri 1988).

7.3 EVALUATION OF ALTERNATIVES FOR NORTH HARBOR ISLAND

The indicator chemicals mercury and total PCBs were selected to represent the nature and extent of contamination at North Harbor Island. The approximate areal extent of sediments which exceed sediment cleanup goals based on mercury and total PCB concentrations is presented in Figure 28. Concentrations of indicator chemicals were assumed to vary linearly between and away from sampling stations for interpolation of problem area boundaries. Sediments exceeding sediment cleanup goals in the North Harbor Island problem area cover an area of approximately 370,000 yd^2. The vertical extent of contaminated sediments which exceeded sediment cleanup goals is not defined, because sediment core data are not available. A depth of 3 ft is assumed for contaminated sediments exceeding sediment cleanup goals. The assumed depth of 3 ft produces a volume of 370,000 yd^3 for use in evaluating candidate sediment remedial alternatives. The actual implementation of a sediment remedial alternative over a larger or smaller area may prove to be more feasible or cost-effective when mobilization, disposal site acquisition and development, and treatment technologies are considered. For example, if a feasible treatment technology is developed for the particular suite of contaminants found in the North Harbor Island problem area, dredging sediments from additional problem areas with similar contaminants may help defray initial costs for the treatment technology development.

In addition to the indicator chemicals mercury and total PCBs, sediments in the North Harbor Island problem area exceeded target cleanup goals for the compounds listed in Table 3. The indicator chemicals were the most widely distributed contaminants. However, the evaluation of treatment technologies must also address additional contaminants that exceed target cleanup goals (i.e., copper, polycyclic aromatic hydrocarbons, 2,4-dimethyl-

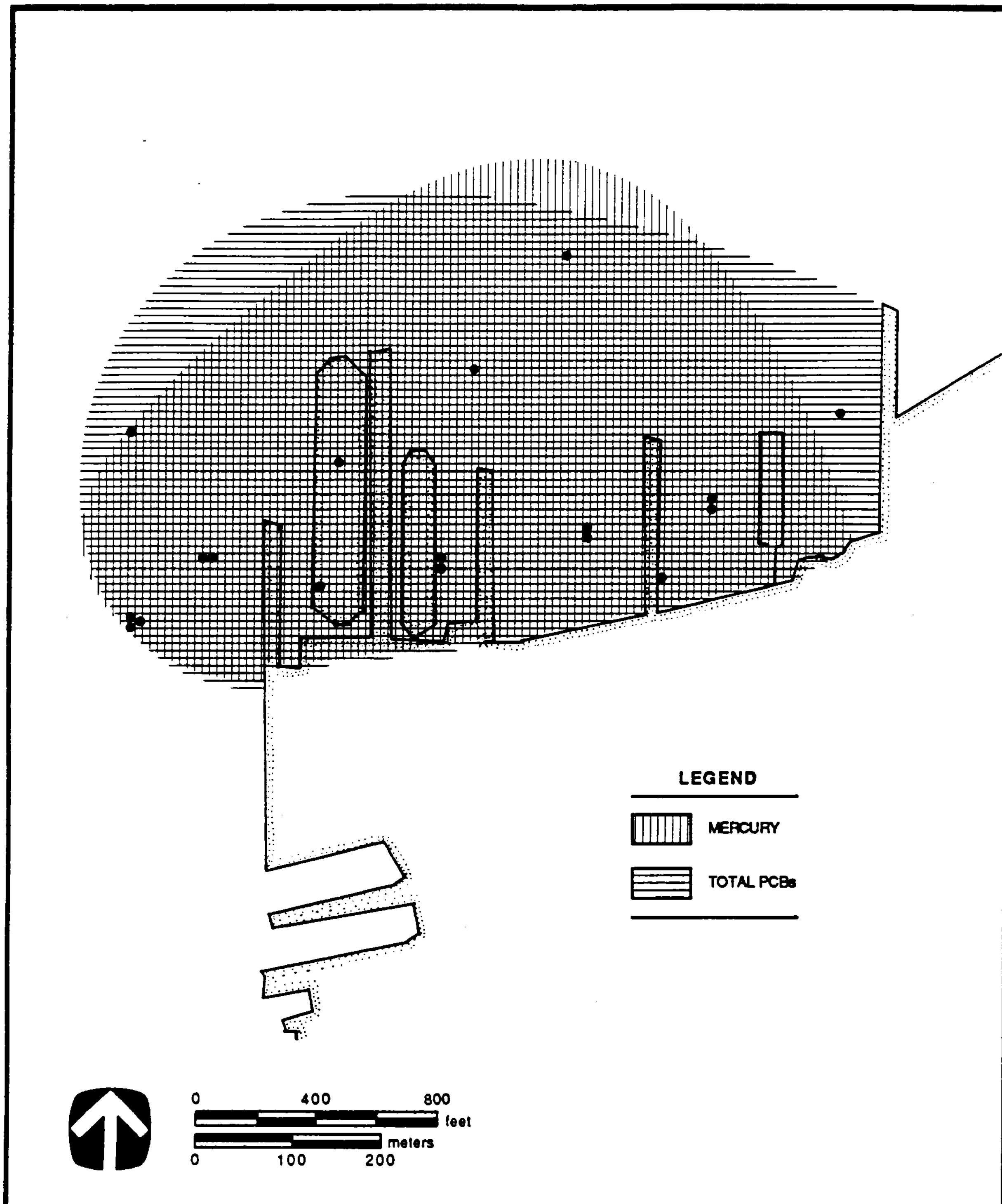

Figure 28. Approximate areal extent of sediments exceeding sediment cleanup goals in North Harbor Island problem area.

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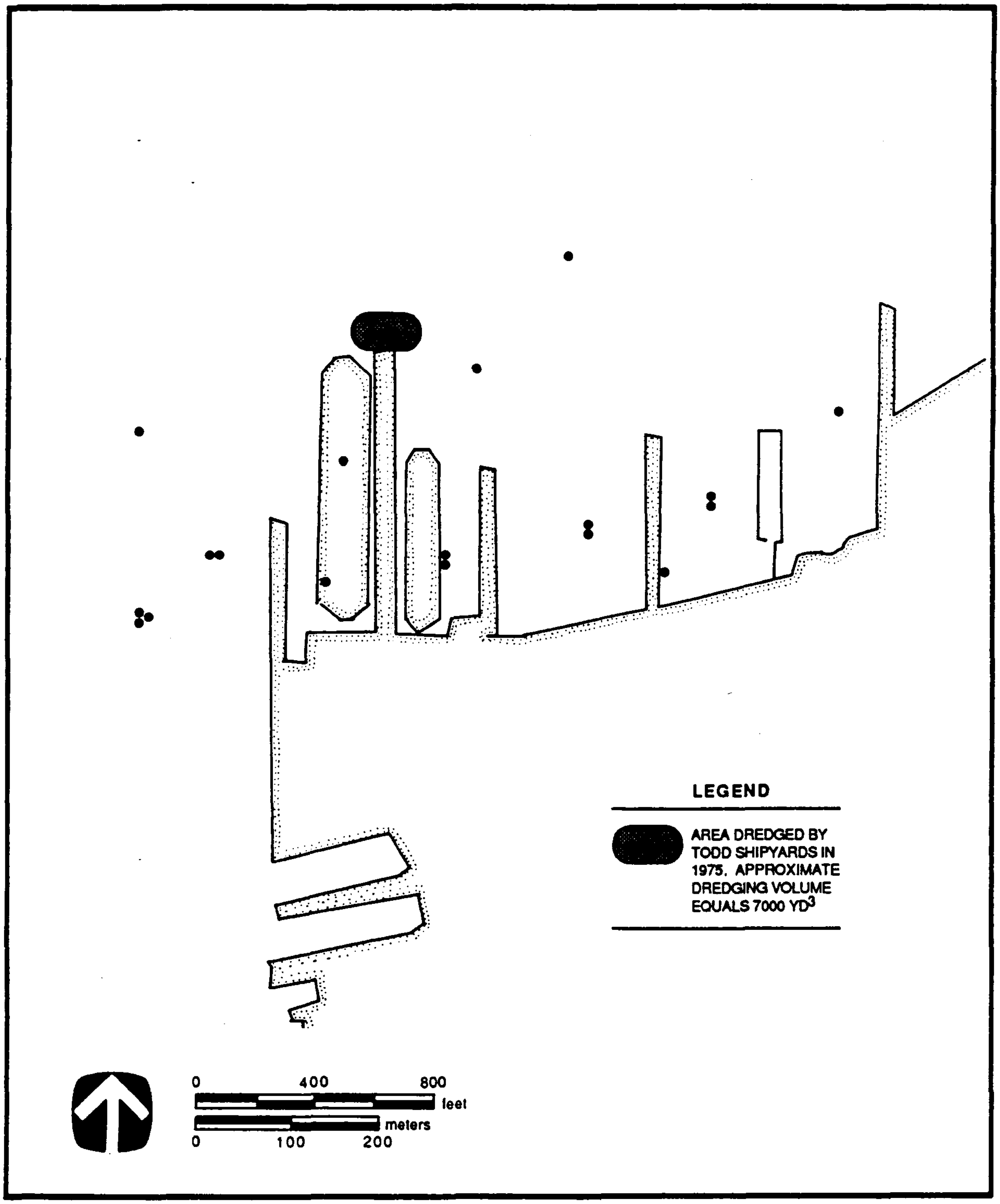

Figure 29. Previous dredging projects in the North Harbor Island problem area.

phenol). Treatment technologies used to remediate organic and inorganic contamination are appropriate for the North Harbor Island problem area. Unfortunately, most treatment technologies have displayed only limited effectiveness when treating both organic and inorganic contaminants simultaneously. Thermal and land treatment are inappropriate for the remediation of inorganic contaminants at the concentrations measured in sediments in the North Harbor Island problem area. Therefore, the candidate alternatives involving these technologies are not considered further. Solidification and solvent extraction are retained for further evaluation. Bench and pilot scale testing that may be required before implementing treatment technologies. Volatile organic contaminants (e.g., xylenes) were among contaminants measured in the problem area at relatively high concentrations (PTI and Tetra Tech 1988). Volatile organic contaminants should not present a major obstacle to the implementation of a sediment remedial alternative. Monitoring will be necessary to determine if volatile organic compounds are potentially harmful, or if volatile organic compounds warrant use of a treatment technology (e.g., air stripping).

Sediments with concentrations of indicator chemicals exceeding sediment cleanup goals in the North Harbor Island problem area were measured at depths ranging from intertidal to approximately 165 ft at Station 10016 (Figure 15) (Malins et al. 1979). Clamshell dredging is only possible to depths of approximately 100 ft, and hydraulic dredging is limited to depths of 50 ft or less. Candidate sediment remedial alternatives that involve hydraulic dredging as a component technology were not retained for further evaluation. Instead, clamshell dredging was retained as the removal technology for sediment remedial alternatives which include sediment removal. The technical feasibility of the remedial alternatives that involve sediment removal is downgraded because of the depths associated with sediments that exceed sediment cleanup goals.

Businesses utilizing the north end of Harbor Island include an active shipyard (Todd), an oil unloading and transfer facility, and the Puget Sound Tug and Barge Company (Figure 14). The only site within the North Harbor Island problem area where previous dredging has been documented based on a review of available dredging permits (Tetra Tech in preparation) is shown in

Figure 29. Shipping activity in the area must be considered when evaluating dredging and capping remedial alternatives. Dredging activities must be implemented during periods of minimal disruption by shipping activities. A spokesperson for Todd Pacific Shipyards indicated that maintenance dredging is required in some areas of the facility (Petrovic, B., 27 April 1988, personal communication), and that in situ capping of contaminated sediments may adversely impact the facility. In situ capping is not retained for further evaluation because of maintenance dredging requirements.

Seven of twelve candidate sediment remedial alternatives are evaluated below for the North Harbor Island problem area. The candidate sediment remedial alternatives selected for evaluation in the North Harbor Island problem area include the following:

- No action
- Institutional controls
- Clamshell dredging/confined aquatic disposal
- Clamshell dredging/nearshore disposal
- Clamshell dredging/upland disposal
- Clamshell dredging/solidification/upland disposal
- Clamshell dredging/solvent extraction/upland disposal.

A narrative matrix assessing each of the above alternatives based on effectiveness, implementability, and cost is presented in Table 13. The narrative matrix is similar to that presented in Table 11 for the Denny Way problem area. A comparative evaluation of sediment remedial alternatives for the North Harbor Island problem area based on ratings of high, moderate, and low in the various subcategories of evaluation criteria is presented in Table 14. Subcategories of evaluation criteria include short-term protectiveness; timeliness; long-term protectiveness; reduction in toxicity,

TABLE 13. REMEDIAL ALTERNATIVES EVALUATION MATRIX FOR THE NORTH HARBOR ISLAND PROBLEM AREA

			NO ACTION	INSTITUTIONAL CONTROLS	CLAMSHELL DREDGE/ NEARSHORE DISPOSAL	CLAMSHELL DREDGE/ UPLAND DISPOSAL	CLAMSHELL DREDGE/ SOLIDIFICATION/ UPLAND DISPOSAL	CLAMSHELL DREDGE/ CONFINED AQUATIC DISPOSAL	CLAMSHELL DREDGE/ SOLVENT EXTRACTION/ UPLAND DISPOSAL
EFFECTIVENESS	SHORT-TERM PROTECTIVENESS	COMMUNITY PROTECTION DURING IMPLEMENTATION	NA	There are no elements of institutional control measures that have the potential to cause harm during implementation.	Public access to dredge and disposal sites is restricted. Public exposure potential is low.	Public access to dredge and disposal sites is restricted. Exposure from CDM spills or mishandling is possible, but overall potential is low.	Public access to dredge, treatment, and disposal sites is restricted. Exposure from CDM spills or mishandling is possible, but overall potential is low. Extended duration of operation may result in moderate exposure potential.	Public access to dredge and disposal sites is restricted. Community exposure is negligible.	Public access to dredge, treatment, and disposal sites is restricted. Extended duration of treatment operations may result in moderate exposure potential.
EFFECTIVENESS	SHORT-TERM PROTECTIVENESS	WORKER PROTECTION DURING IMPLEMENTATION	NA	There are no elements of institutional control measures that have the potential to cause harm during implementation.	Operational controls can be implemented during dredging and transport to minimize potential for worker exposure. Workers wear protective gear.	Additional CDM handling increases possibility of spills or mishandling. Overall exposure potential is low. Operational controls can be implemented during dredging and transport to minimize potential for worker exposure. Workers wear protective gear.	Additional CDM handling associated with treatment may increase exposure potential. Workers wear protective gear.	Operational controls can be implemented during dredging and transport to minimize potential for worker exposure. Workers wear protective gear.	Additional CDM handling associated with treatment increases worker risk over dredge/disposal options. Workers wear protective gear.
EFFECTIVENESS	SHORT-TERM PROTECTIVENESS	ENVIRONMENTAL PROTECTION DURING IMPLEMENTATION	Original contamination remains. Source inputs continue. Adverse biological impacts continue.	Source control is implemented. Contaminants remain and adverse biological impacts continue at existing levels.	Existing contaminated habitat is destroyed. Nearshore disposal habitat is lost. Contaminated sediment is resuspended.	Existing contaminated habitat is destroyed. Contaminated sediment is resuspended during dredging operations. Dredge water management is improved over hydraulic dredging.	Existing contaminated habitat is destroyed. Contaminated sediment is resuspended during dredging operations.	Existing contaminated habitat and disposal site habitat are destroyed. Contaminated sediment is resuspended during dredging and disposal operations. Dredge water management is improved over hydraulic dredging.	Existing contaminated habitat is destroyed. Contaminated sediment is resuspended during dredging operations.
EFFECTIVENESS	TIMELINESS	TIMELINESS	The no action alternative is in force in the absence of any other action. Sediments are unlikely to recover in the absence of source control.	Access restrictions and monitoring efforts can be implemented quickly. Source controls can be implemented within 1 to 2 years. Partial sediment recovery is achieved naturally, but significant contaminant levels persist.	Dredge and disposal operations could be accomplished within approximately 2 years. Disposal siting and facility construction delay implementation.	Dredge and disposal operations could be accomplished within approximately 2 years. Disposal siting and facility construction delay implementation.	Bench and pilot scale testing are required. Full scale equipment is available. Remediation could be accomplished within 1 to 2 years.	CAD can be accomplished within approximately 1 to 2 years.	Bench and pilot scale testing are required. Full scale equipment is available. Remediation could be accomplished within 1 to 2 years.
EFFECTIVENESS	LONG-TERM PROTECTIVENESS	LONG-TERM RELIABILITY OF CONTAINMENT FACILITY	CDM containment is not an aspect of this alternative.	CDM containment is not an aspect of this alternative.	Nearshore confinement facilities structurally reliable. Dike and cap repairs can be readily accomplished.	Upland confinement facilities may be considered structurally reliable. Dike and cap repairs can be readily accomplished. Underdrain or liner cannot be repaired.	Upland confinement facilities may be considered structurally reliable. Treated CDM may be suitable for use as inert construction material or disposal at a standard solid waste landfill.	The long-term reliability of the cap to prevent contaminant reexposure in the absence of physical disruption is considered acceptable.	Treated CDM low in metals can be used as inert construction material or disposed of at a standard solid waste landfill.
EFFECTIVENESS	LONG-TERM PROTECTIVENESS	PROTECTION OF PUBLIC HEALTH	The potential for exposure to harmful sediment contaminants via ingestion of contaminated food species remains.	The potential for exposure to harmful sediment contaminants via ingestion of contaminated food species remains, albeit at a reduced level as a result of consumer warnings and source controls.	The confinement system precludes public exposure to contaminants by isolating CDM. Variable physicochemical conditions in the fill increase potential for contaminant migration over CAD.	The confinement system precludes public exposure to contaminants by isolating CDM. The potential for groundwater contamination is low. Upland disposal facilities are more secure than nearshore facilities.	Harmful contaminants are bound in the treated CDM. The potential for groundwater contamination is low. Permanent treatment for contaminants is not effected.	The confinement system precludes public exposure to contaminants by isolating contaminated sediments from the overlying biota. Protection is adequate.	Harmful organic contaminants are removed from CDM. Concentrated contaminants are disposed of by RCRA- approved treatment or disposal. Permanent treatment for organic contaminants is effected.
EFFECTIVENESS	LONG-TERM PROTECTIVENESS	PROTECTION OF ENVIRONMENT	Original contamination remains. Source inputs continue. Exposure potential remains at existing levels or increases.	Original contamination remains. Source inputs are controlled. Adverse biological effects continue but decline slowly as a result of sediment recovery and source control.	The confinement system precludes environmental exposure to contaminated sediment. The potential for contaminant migration into marine environment is increased over CAD.	Upland disposal is secure, with negligible potential for environmental impact if properly designed. Potential for shallow groundwater contamination exists.	Upland disposal is secure, contaminant monitoring is improved over nearshore. Potential for shallow groundwater contamination exists.	The confinement system precludes environmental exposure to contaminated sediment. Thickness of overlying cap prevents exposure of burrowing organisms. Potential for contaminant migration is low because CDM is maintained at in situ conditions.	Harmful organic contaminants are removed from CDM. Concentrated contaminants are disposed of by RCRA- approved treatment or disposal. Residual contamination is reduced below harmful levels.
EFFECTIVENESS	CONTAMINANT MIGRATION	REDUCTION IN TOXICITY, MOBILITY, AND VOLUME	Sediment toxicity and contaminant mobility are expected to remain at current levels or increase as a result of continued source inputs. Contaminated sediment volume increases as a result of continued source inputs.	Sediment toxicity is expected to decline slowly with time as a result of source input reductions and sediment recovery. Contaminant mobility is unaffected. Volume of contaminated sediment remains at preremediation level or declines.	The toxicity of CDM in the confinement zone remains at preremediation levels. Altered conditions resulting from dredge/disposal operations may increase mobility of metals. Volume of contaminated sediments is not reduced.	The toxicity of CDM in the confinement zone remains at preremediation levels. The potential for migration of metals is greater for upland disposal than for CAD or nearshore disposal. Volume of contaminated sediments is not reduced.	The toxicity of treated CDM is not reduced. Mobility of contaminants is reduced. Volume of CDM for disposal increases.	The toxicity and mobility of contaminated sediments in the confinement zone remains at preremediation levels. Volume of CDM is not reduced.	Harmful contaminants are removed from CDM. Concentrated contaminants are disposed of by RCRA- approved treatment or disposal. Toxicity and mobility considerations are eliminated. Volume of contaminated material is substantially reduced.

TABLE 13. (CONTINUED).

			NO ACTION	INSTITUTIONAL CONTROLS	CLAMSHELL DREDGE/ NEARSHORE DISPOSAL	CLAMSHELL DREDGE/ UPLAND DISPOSAL	CLAMSHELL DREDGE/ SOLIDIFICATION/ UPLAND DISPOSAL	CLAMSHELL DREDGE/ CONFINED AQUATIC DISPOSAL	CLAMSHELL DREDGE/ SOLVENT EXTRACTION/ UPLAND DISPOSAL
IMPLEMENTABILITY	TECHNICAL FEASIBILITY	FEASIBILITY AND RELIABILITY OF REMEDIAL ACTION PROCESS OPTIONS	Implementation of this alternative is *feasible and reliable.*	Source control and institutional *control measures are feasible* and reliable. Source control reliability assumes all sources can be identified.	Clamshell dredges and split-*hulled barges are conventional* and reliable equipment. Nearshore confinement of CDM has been successfully accomplished.	Clamshell dredges and split-*hulled barges are conventional* and reliable equipment. Secure upland confinement technology is well developed.	Clamshell dredges and split-*hulled barges are conventional* and reliable equipment. Solidification process would require bench and pilot scale testing to determine reliability and feasibility of large scale process.	Clamshell dredges and split-hulled barges are conventional and reliable equipment. CAD of contaminated sediments is feasible and reliable. CAD is a demonstrated containment technology.	Sludges, soils, and sediments *have successfully been treated* using this technology.
		IMPLEMENTATION OF MONITORING PROGRAMS	No monitoring over and above programs established under other authorities are implemented.	Sediment monitoring schemes can be readily implemented. Adequate coverage of problem area would require an extensive program.	Monitoring can be readily implemented to detect contaminant migration through dikes. Improved confinement enhances monitoring compared with CAD.	Monitoring can be readily implemented to detect contaminant migration through dikes. Improved confinement enhances monitoring over CAD. Installation of monitoring systems is routine aspect of facility siting.	Monitoring can be readily implemented to detect contaminant migration.	Confinement reduces monitoring requirements in comparison to institutional controls. Sediment monitoring schemes can be readily implemented.	Monitoring is required only to evaluate the reestablishment of benthic communities. Monitoring programs can be readily implemented.
		IMPLEMENTATION OF OPERATING AND MAINTENANCE PROGRAMS	There are no O & M requirements associated with the no action alternative.	O & M requirements are minimal. Some O & M is associated with monitoring, maintenance of warning signs, and issuance of ongoing health advisories.	O & M requirements consist of inspections, groundskeeping, and maintenance of monitoring equipment.	O & M requirements consist of inspections, groundskeeping, and maintenance of monitoring equipment.	O & M costs are minimal at the conclusion of CDM treatment. System maintenance is intensive during implementation.	O & M requirements are minimal. Some O & M associated with monitoring.	No O & M costs are incurred at the conclusion of CDM treatment. System maintenance is intensive during implementation.
	INSTITUTIONAL FEASIBILITY	APPROVAL OF RELEVANT AGENCIES	Approval is denied as a result of agency commitments to mitigate *observed biological effects.*	Requirements for agency approvals are minimal and are ex*pected to be readily obtainable.*	Approvals from the City of Seattle, COE, EPA, and state *agencies are feasible.* Availability of approvals for facility siting are uncertain but are assumed feasible. However, disposal of untreated CDM is considered less desirable than if CDM is treated.	Approvals from the City of Seattle, COE, EPA, and state *agencies are feasible.* Coordination is required for establishing discharge criteria for dredge water maintenance. However, disposal of untreated CDM is considered less desirable than if CDM is treated.	Approvals depend largely on result of pilot testing and nature *of the material following treat*ment.	Approvals from the City of Seattle, COE, EPA, and state agencies are feasible. However, disposal of untreated CDM is considered less desirable than if CDM is treated.	Approvals depend largely on results of pilot testing and the na*ture of treatment residuals.*
		COMPLIANCE WITH CHEMICAL- AND LOCATION-SPECIFIC ARARS AND GUIDELINES	AET levels in sediments are exceeded. No permit requirements exist. This alternative fails to meet the intent of NCP because of ongoing impacts.	AET levels in sediments are exceeded. This alternative fails to meet intent of NCP because of ongoing impacts. State requirements for source control are achieved. Coordination with Seattle-King County Health Department for health advisories for seafood consumption.	WISHA/OSHA worker protection required. Sections 401 and 404, hydraulics, and Shoreline Management permits are required. Shoreline development permit required for disposal siting.	WISHA/OSHA worker protection required. Sections 401 and 404, hydraulics, and Shoreline Management permits are required.	WISHA/OSHA worker protection required. Sections 401 and 404, hydraulics, and Shoreline Management permits are required. Requires approval from Seattle-King County Health Department for disposal.	WISHA/OSHA worker protection required. Sections 401 and 404, hydraulics, and Shoreline Management permits are required.	WISHA/OSHA worker protection required. Section 404 permit is required. Alternative complies with EPA policy for permanent reduction in contaminant mobility. Requires RCRA permit for disposal of concentrated organic waste.
	AVAILABILITY	AVAILABILITY OF SITES, EQUIPMENT, AND METHODS	All materials and procedures are available.	All materials and procedures are available to implement institutional controls.	Equipment and methods to implement alternative are readily available. Potential nearshore disposal sites have been identified but none are currently available.	Equipment and methods to implement alternative are readily available. Potential upland disposal sites have not been identified for disposal of untreated CDM.	Equipment and methods to implement alternative are readily available. Upland disposal sites are potentially available.	Equipment and methods to implement alternative are readily available. Open water CAD sites are potentially available.	Process equipment available. Disposal site availability is not a primary concern because of reduction in hazardous nature of material.

TABLE 14. EVALUATION SUMMARY FOR NORTH HARBOR ISLAND PROBLEM AREA

	No action	Institutional Controls	Clamshell/ CAD	Clamshell/ Nearshore Disposal	Clamshell/ Upland Disposal	Clamshell/ Solidification/ Upland Disposal	Clamshell/ Solvent Extraction/ Upland Disposal
Short-Term Protectiveness	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate
Timeliness	Low	Low	High	Moderate	Moderate	Moderate	Moderate
Long-Term Protectiveness	Low	Low	High	Moderate	Moderate	High	High
Reduction in Toxicity, Mobility, or Volume	Low	Low	Low	Low	Low	Moderate	High
Technical Feasibility	High	High	Moderate	Moderate	Moderate	Moderate	Moderate
Institutional Feasibility	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate
Availability	High	High	Low	Low	Low	Moderate	Moderate
Estimated Cost							
Initial	---	30,000	1,500,000	4,300,000	13,000,000	22,000,000	74,000,000
O & M	---	610,000	2,300,000	560,000	900,000	700,000	700,000
Total	---	640,000	3,800,000	4,900,000	14,000,000	23,000,000	75,000,000

mobility, and volume; technical feasibility; institutional feasibility; availability; capital costs; and O&M costs. Remedial costs are based on the estimated volume of sediments that exceed sediment cleanup goals in the North Harbor Island problem area (Figure 28).

7.3.1 Short-Term Protectiveness

The no action and institutional controls alternatives rated low for the short-term protectiveness criterion. In the absence of remedial action or implementation of source controls, contaminant inputs will continue at pre-remediation levels and exposure potential will remain at unacceptable levels. Implementation of the institutional controls alternative will decrease the level of contaminant inputs over the long-term, but sediments will remain unacceptably contaminated and exposure potential will remain over the short-term.

All sediment remedial alternatives which involve dredging of contaminated sediments received a moderate rating under the short-term protectiveness criterion, primarily due to the potential for resuspension of contaminated sediment. Confined aquatic disposal of sediments would also resuspend sediments during the disposal phase of remediation. Alternatives that include either solidification or solvent extraction as a treatment technology require additional handling of contaminated dredge material, increasing the potential for community or worker exposure.

All the sediment remedial alternatives would destroy the existing benthic habitat over the short-term, except for the no action and institutional controls alternatives. Alternatives that involve sediment removal and disposal in either a confined aquatic, nearshore, or upland disposal facility also require additional land. One possible positive tradeoff on the additional land use required for confined aquatic disposal is the placement of contaminated sediments in a separate problem area in Elliott Bay and confining the contaminated sediments from two problem areas under a single cap.

7.3.2 Timeliness

The no action and institutional controls alternatives were rated low under the timeliness criterion. With no action, sediments remain unacceptably contaminated, source inputs continue, and natural sediment recovery is unlikely. Source inputs are controlled under the institutional controls alternative, but as discussed in Section 3.2.4, sediment recovery based on the enrichment ratios for total PCBs, mercury, and 4,4'-DDD is estimated to be improbable within an acceptable timeframe.

Moderate ratings were assigned to alternatives involving clamshell dredging and nearshore or upland disposal. Obtaining approvals and construction of a confined nearshore or upland facility for untreated contaminated dredge material would likely take from 1-2 yr. Equipment and methods will not require development. Pre-implementation modeling and testing is not expected to be extensive. Development of a treatment technology for managing contaminated dredge water at the disposal site is not expected to require an extensive period of time for testing or development. The period estimated for the implementation of either of these alternatives is from 2-4 yr.

The alternatives involving solidification and solvent extraction also received a moderate rating under the timeliness criterion. The treatment technologies are expected to require an extensive period of testing prior to acceptance. Assuming a treatment rate of 500 yd^3/day, treatment of the contaminated sediments from the North Harbor Island problem area would require approximately 2 yr.

The clamshell dredging/CAD alternative received a high rating under the timeliness criterion. Clean sediments are assumed to be readily available for the capping of contaminated dredge material. Once a confined aquatic disposal site is designated, implementation of this alternative would be feasible within approximately 1 yr.

7.3.3 Long-Term Protectiveness

The long-term protectiveness evaluation resulted in the assignment of low ratings to the no action and institutional controls alternatives for the North Harbor Island problem area. The timeframe for sediment recovery is too long to expect more than minimal improvements in the contaminated sediments with institutional controls. Contaminated sediments would remain after the implementation of source controls, though contaminant concentrations would gradually decline. Biological impacts (e.g., bioaccumulation, decreased benthic abundance) would continue, and the potential for community exposure would remain at unacceptable levels.

Alternatives involving nearshore or upland disposal of untreated sediments received moderate ratings under the long-term protectiveness criterion. The physicochemical changes, primarily in redox potential, will increase the potential for contaminant migration when contaminated sediments are moved to a different environment. The migration potential can be modeled following dredge material testing to help determine the engineering controls required to ensure reliability of the containment structure. A nearshore facility would also be exposed to wave and tidal action which requires that a structurally reliable facility be constructed. The long-term success of nearshore disposal for the isolation and containment of contaminated sediment has not been demonstrated. Upland disposal facilities are generally considered to be the most secure disposal option because of the availability of engineering controls. However, the potential for impacts on groundwater resources will still remain over the long-term due to the migration and leaching potential of contaminated dredge material.

The clamshell dredging/solidification/upland disposal and clamshell dredging/solvent extraction/upland disposal alternatives received a high rating under the evaluation for long-term protectiveness. Both alternatives should prove feasible in the treatment of contaminated dredge material from the North Harbor Island problem area. Testing and modeling of the long-term leaching potential of solidified material will be required. The solvent extraction process should be successful for the removal of organics and isolation of metals.

The alternative involving confined aquatic disposal received a high rating for the long-term protectiveness criterion. Cap thickness can be maintained over the long-term to assure isolation of the contaminated sediments and for preventing exposure of sensitive organisms. The physicochemical state of the contaminated dredge material is maintained, so the potential for migration is less than the potential for migration with nearshore or upland disposal.

7.3.4 Reduction in Toxicity, Mobility, and Volume

All alternatives except those involving post removal sediment treatment received low ratings under the evaluation criterion for reducing toxicity, mobility, and volume. In the absence of treatment, the toxicity, mobility, and volume of contaminants in North Harbor Island sediments would remain.

The clamshell dredging/solidification/upland disposal alternative received a moderate rating under the criterion for reduction of toxicity, mobility, and volume. The toxicity of contaminated dredge material would be lowered by the solidification process, however, the contaminants would remain unaltered and potential toxicity would be unchanged. The mobility of contaminants would be decreased through the solidification process, but the volume of material for disposal would increase.

The clamshell dredging/solvent extraction/upland disposal alternative received a high rating under the evaluation criterion for reducing toxicity, mobility, and volume. The toxicity and mobility of contaminants in contaminated dredge material are reduced through the removal of contaminants. The volume of contaminated material requiring disposal would be reduced to the amount of material generated during the treatment process.

7.3.5 Technical Feasibility

The no action and institutional controls alternatives were rated high under the technical feasibility criterion. The no action criterion is by definition technically feasible. Institutional controls are considered to have a high degree of technical feasibility.

All alternatives that involve removal of contaminated sediments from the North Harbor Island problem area received a moderate rating under the evaluation for technical feasibility. The depths at which contaminated sediments are found (up to 165 ft) dictate that if sediment removal is a component of the sediment remedial alternative selected, a dredging technique suitable for depths below 100 ft must be used.

7.3.6 Institutional Feasibility

The no action and institutional controls alternatives were assigned low ratings under the institutional feasibility criterion. Long-term protection of public health and the environment are not accomplished through the implementation of either alternative. Neither of the alternatives would comply with the mandate of the Puget Sound Water Quality Authority for improving the quality of Puget Sound.

Moderate ratings were assigned to the remaining alternatives for a variety of reasons. Although the disposal options for contaminated sediments are expected to be resolved in the future, there is significant uncertainty at this time regarding potential aquatic, nearshore, and upland disposal facility availability. Potential difficulties may arise in obtaining approval for treatment sites and implementation of treatment technologies.

7.3.7 Availability

The no action and institutional controls alternatives received a high rating for availability because they can be readily implemented. The no action and institutional controls alternatives do not depend on equipment or disposal site availability, so there are no obstacles to implementation.

Under the availability criterion, low ratings were assigned to alternatives that involve disposal of contaminated sediment from the North Harbor Island problem area in nearshore, upland, or confined aquatic disposal sites. Candidate alternatives were developed under the assumption that nearshore, upland, and confined aquatic disposal sites will be available. However, there are no sites currently approved for use and no approved sites are currently under construction. The equipment and expertise required to implement the clamshell dredging/CAD, clamshell dredging/near-shore disposal, and clamshell dredging/upland disposal alternatives are readily available.

The sediment remedial alternatives involving solidification or solvent extraction and disposal at an upland facility were rated moderate under the availability criterion. Availability of equipment and expertise are not expected to present any obstacles to the implementation of either of these alternatives. Development and construction of a treatment facility will require acquisition of a suitable site, which will be the major obstacle to the implementation of treatment alternatives. Assuming that treatment technologies are successful, disposal at an upland facility such as Coal Creek is possible.

7.3.8 Cost

The assumptions used for costing sediment remedial alternatives are presented in Section 7.1.8 and Appendix D. Total costs of sediment remedial alternatives for the North Harbor Island problem area are presented in Table 14. A breakdown of the initial and O&M costs for the candidate alternatives is presented in Appendix D. Costs for the candidate sediment remedial alternatives are presented in order of lowest to highest initial cost.

Initial costs for implementation of the institutional controls alternative include those costs required to access restriction signs. Environmental monitoring and educational program costs (i.e., O&M costs) associated with this alternative are similar to O&M costs for alternatives involving nearshore or upland disposal.

The initial costs for the clamshell dredging/confined aquatic disposal alternative are less than initial costs associated with all other alternatives involving removal and disposal. However, the O&M costs for the environmental monitoring and maintenance of a CAD site are greater than the O&M costs for monitoring and maintenance of upland or nearshore disposal facilities.

Initial costs for implementing the clamshell dredging/nearshore disposal alternative at the North Harbor Island problem area are greater than the clamshell dredging/confined aquatic disposal alternative primarily due to costs associated with construction of the disposal facility. The initial costs for the construction of a nearshore disposal facility are partially offset by the reduced O&M costs for the clamshell dredging/nearshore disposal alternative relative to the clamshell dredging/confined aquatic disposal alternative. However, the total costs are slightly greater for the nearshore disposal alternative.

The clamshell dredging/upland disposal alternative requires increased initial costs for construction compared to confined aquatic and nearshore disposal alternatives. The O&M costs for upland disposal facilities are greater than O&M costs for nearshore facilities because the assumed fill depth results in a larger area for monitoring and maintenance. However, the O&M costs for upland disposal facilities are lower than O&M costs for confined aquatic disposal sites because monitoring and maintenance are more easily implemented.

The alternatives involving solidification or solvent extraction technologies have a high initial cost, because the treatment technologies require facility development and construction, and the technologies themselves have a high unit cost. Operation and maintenance costs are similar to many of the other candidate alternatives. The initial costs for alternatives involving treatment technologies are not considered to be cost-effective when compared with other candidate sediment remedial alternatives for the North Harbor Island problem area.

7.4 PREFERRED ALTERNATIVE FOR NORTH HARBOR ISLAND

The clamshell dredging/confined aquatic disposal alternative was selected as the preferred alternative for the North Harbor Island problem area based on the evaluation summary and estimated cost. This alternative rated high for long-term protectiveness and timeliness. Long-term protectiveness is assumed to be better for this alternative than alternatives involving nearshore or upland disposal. The long-term protectiveness is similar to the long-term protectiveness of treatment technologies because of the isolation of contaminated sediments at in situ conditions. The high rating for timeliness is based on the relative time required to implement this alternative when compared with other alternatives.

The low rating for availability was weighted heavily by the lack of a designated confined aquatic disposal site. As discussed earlier in this report, designation of a confined aquatic disposal site is anticipated for Elliott Bay. The clamshell dredging/confined aquatic disposal alternative was given moderate ratings for technical and institutional feasibility, and short-term protectiveness. All other alternatives were assigned a similar rating under these criteria.

The low rating for reduction in toxicity, mobility, and volume indicates that the contamination problem in the sediments from the North Harbor Island will remain. The application of a treatment technology or natural processes are the only methods for reduction in toxicity, mobility and volume. Treatment technologies may be developed which are cost-effective for the remediation of contaminant sediments. Until a cost-effective treatment technology for simultaneously treating organic and inorganic wastes in sediment is developed, implementation of sediment remedial alternatives involving treatment technologies is not practical.

REFERENCES

Armstrong, J.W., R.H. Thom, K.K. Chew, B. Arpke, R. Bohn, J. Glock, R. Hieronymus, E. Hurlbert, K. Johnson, B. Mayer, B. Stevens, S. Tettlebach, and P. Waterstrat. 1978. The impact of the Denny Way combined sewer overflow on the adjacent flora and fauna in Elliott Bay, Puget Sound, Washington. Municipality of Metropolitan Seattle, Seattle, WA. 102 pp.

Austin, D. 22 January 1988. Personal Communication (phone by Mr. Merv Coover). Resource Conservation Company, Bellevue, WA.

Black and Veatch. 1985. Preliminary investigation - Phase I descriptions of current conditions. Prepared for Washington Department of Ecology, Olympia, WA. Black and Veatch, Tacoma, WA.

Brannon, J.M., R.E. Hoeppel, T.C. Sturgis, I. Smith, Jr., and D. Gunnison. 1985. Effectiveness of capping in isolating contaminated dredged material from biota and the overlying water. Technical Report D-85-10, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Brannon, J.M., R.E. Hoeppel, T.C. Sturgis, I. Smith, Jr., and D. Gunnison. 1986. Effectiveness of capping isolating dutch kills sediment from biota and the overlying water. Miscellaneous Paper D-86-2, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Burke, S. 13 April 1988. Personal Communication (phone by Mr. John Virgin). King County Health Department, Seattle, WA.

Cargill, D. 27 April 1988. Personal Communication (phone by Ms. Karen Keeley). Washington Department of Ecology, Olympia, WA.

Carpenter, R., M.L. Peterson, and J.T. Bennet. 1985. Pb-derived sediment accumulation and mixing rates for the greater Puget Sound Region. Mar. Geol. 64:291-312.

Chapman, P.M., G.A. Vigers, M.A. Farrell, R.N. Dexter, E.A. Quinlan, R.M. Kocan, and M.L. Landolt. 1982. Survey of biological effects of toxicants upon Puget Sound biota. I: Borad scale toxicity survey. NOAA Technical Memorandum OMPA-25. National Oceanic and Atmospheric Administration, Boulder, CO. 98 pp.

Code of Federal Regulations. 1987. Protection of environment Title 40, Section 261.3. Office of Federal Register, National Archives and Records Administration. U.S. Government Printing Office, Washington, DC.

Comiskey, C.E., T.A. Farmer, C.C. Brandt, and G.P. Romberg. 1984. Toxicant pretreatment planning study Technical Report C2: Puget Sound benthic studies and ecological implications. Municipality of Metropolitan Seattle, Seattle, WA. 373 pp.

Conner, J. 18 November 1987. Personal Communication (phone by Mr. Merv Coover). Chemical Waste Management, Riverdale, IL.

Cooley, R., R. Matasci, M. Merrill, and Brown and Caldwell. 1984. Collection system evaluation. Toxicant pretreatment planning study Technical Report A-2. Municipality of Metropolitan Seattle Toxicant Program Report No. 4B. Metro, Seattle, WA. 100 pp.

Cullinane, J. 18 November 1987. Personal Communication (phone by Mr. Merv Coover). U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Cullinane, J. 8 January 1988. Personal Communication (phone by Mr. Merv Coover). U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Dexter, R.N., D.E. Anderson, E.A. Quinlan, L.S. Goldstein, R.M. Strickland, S.P. Pavlou,and J.R. Clayton. 1981. A summary of knowledge of Puget Sound related to chemical contaminants. NOAA Tech. Memo OMPA-13. Prepared for National Oceanic and Atmospheric Administration by URS Company, Seattle, WA. 434 pp.

Francinques, N.R. 1985. Identification of promising concepts for treatment of contaminated sediments. pp. 162-185. In: Management of Bottom Sediments Containing Toxic Substances. Proceedings of the 10th U.S./Japan Experts Meeting. T.R. Patin (ed). Water Resources Support Center, Fort Belvoir, VA.

Gamponia, V., T. Hubbard, P. Romberg, T. Sample, and R. Swartz. 1986. Identifying hot spots in the lower Duwamish River using sediment chemistry and distribution patterns. Municipality of Metropolitan Seattle, Seattle, WA.

Gunnison, D., J.M. Brannon, T.C. Sturgis, and I. Smith, Jr. 1987. Development of a simplified column test for evaluation of thickness of capping material required to isolate contaminated dredge material. Miscellaneous Paper D-87-2, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Hayes, D.F. 1985. Guide to selecting a dredge for removal of contaminated bottom sediments. Draft Environmental Effects of Dredging Technical Note, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Hotchkiss, D. 6 April 1988. Personal Communication (phone by Mr. John Virgin). Port of Seattle, Environmental Affairs Division, Seattle, WA.

Kendall, D. 7 January 1988. Personal Communication (phone by Mr. Merv Coover). U.S. Army Corps of Engineers, Regulatory Branch, Seattle, WA.

Ludwig, D.D., J.H. Sherrard, and J.M. Betteker. 1985. Implementation strategies for application of solidification/stabilization technology to dredged material. Environmental Engineering Research Report No. 85-11-01. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Malins, D.C., B.B. McCain, D.W. Brown, A.K. Sparks, and H.O. Hodgins. 1980. Chemical contaminants and biological abnormalities in central and southern Puget Sound. NOAA Technical Memorandum OMPA-2. National Oceanic and Atmospheric Administration, Boulder, CO. 295 pp.

Means. 1988. Means Heany construction cost data. R.S. Means Company, Inc., Kingston, MA.

Morris, J. 18 November 1987. Personal Communication (phone by Mr. Merv Coover). Husky Construction Co., Seattle, WA.

Municipality of Metropolitan Seattle. 1983. Water quality assessment of the Duwamish Estuary, Washington. Prepared by Harper-Owes, Seattle, WA for the Metro, Seattle, WA.

NUS. 1983. Feasibility study - Hudson River PCB site, New York. U.S. EPA Work Assignment No. 01-2V84.0. Contract No. 68-01-6699. NUS, Corporation, Washington, DC.

Nyers, E. 11 November 1987. Personal Communication (phone by Mr. Merv Coover). DETOX, Inc., Dayton, OH.

O'Connor, J.M., and S.G. O'Connor. 1983. Evaluation of the 1980 capping operations at the experimental mud dump site, New York Bight Apex. Technical Report D-83-3, prepared by New York University Medical Center, New York City, and Valley Ecosystems, Warwick, NY, for the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Otsuki, T., and M. Shima. 1984. Soil improvement by deep cement continuous mixing method and its effect on the environment. pp. 215-238. In: Management of Bottom Sediments Containing Toxic Substances, Proceedings of the 8th U.S./Japan Experts Meeting. T.R. Patin (ed). Water Resources Support Center, Fort Belvoir, VA.

Petrovic, Bruce. 27 April 1988. Personal Communication (phone conversation with Mr. John Virgin). Todd Shipyards, Seattle, WA.

Phillips, K.E., J.F. Malek, and W.B. Hamner. 1985. Evaluation of alternative dredging methods and equipment, disposal methods and sites, and site control and treatment practices for contaminated sediments. U.S. Army Corps of Engineers, Seattle, WA.

Porter, J. 1986. U.S. Environmental Protection Agency Interim guidance to agency regional offices discussing issues related to selecting Superfund site remedies. Environment Reporter. p. 1603.

PTI and Tetra Tech. 1988. Elliott Bay Action Program: analysis of toxic problem areas. Draft Report. Prepared for the Puget Sound Estuary Program, U.S. Environmental Protection Agency, Region X. Tetra Tech, Inc., Bellevue, WA. 330 pp. + appendices.

PTI and Tetra Tech. In Preparation. Elliott Bay Action Program: revised action plan. Tetra Tech, Inc., Bellevue, WA.

Puget Sound Dredge Disposal Analysis. 1988. Draft environmental impact statement - proposed unconfined open-water disposal sites for dredged material, Phase 1 (central Puget Sound). PSDDA, U.S. Army Corps of Engineers, Seattle District, Seattle, WA.

Puget Sound Water Quality Authority. 1987. 1987 Puget Sound water quality management plan. Puget Sound Water Quality Authority, Seattle, WA.

Raymond, Gene L. 1983. Sediment resuspension during clamshell dredging. Dredge Material Research, Vol. D-83-1. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Rockey, M. 11 August 1987. Personal Communication (phone by Ms. Glynda J. Steiner). Foss Launch and Tug, Seattle, WA.

Romberg, G.P., S.P. Pavlou, R.F. Shokes, W. Hom, E.A. Crecelius, P. Hamilton, J.T. Gunn, R.D. Muaench, and J. Vinelli. 1984. Presence, distribution and fate of toxicants in Puget Sound and Lake Washington. Toxicant Pretreatment Planning Study. TPPS Technical Report C1, Municipality of Metropolitan Seattle Toxicant Program Report No. 6A. Water Quality Division. 231 pp.

Romberg, G.P., D. Healy, and K. Lund. 1987. Toxicant reduction in the Denny Way combined sewer system. Municipality of Metropolitan Seattle, Seattle, WA.

Romberg, P., and A. Sumeri. 1988. Sediment capping at the Denny Way CSO. Presented at the First Annual Meeting on Puget Sound Research, 18-19 March 1988, Puget Sound Water Quality Authority, Seattle, WA.

Sanderson, W.H., and A.L. McKnight. 1986. Survey of equipment and construction techniques for capping dredged material. Miscellaneous Paper D-86-6, prepared by The Sand Hen Corporation, Wilmington, NC, for the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Schroeder, P.R. 1983. Chemical clarification methods for confined dredged material disposal. Technical Report D-83-2. U.S. Army Corps of Engineers, Washington, DC.

Schroeder, P. 18 November 1987. Personal Communication (phone by Mr. Merv Coover). U.S. Army Corps of Engineers, Vickburg, MS.

Stober, Q.J., and K.K. Chew. 1984. Renton sewage treatment plant project. Duwamish Head. Final report for the period 1 July to 31 December 1984. University of Washington Fisheries Research Institute, Seattle, WA. 370 pp.

Tavolaro, J.F. 1984. A sediment budget study of clamshell dredging and ocean disposal activities in the New York Bight. Environmental Geology and Water Science. Vol. 6, No. 3.

Tetra Tech. 1986. Development of sediment quality values for Puget Sound. Final Report. Prepared for Resource Planning Associates and U.S. Army Corps of Engineers, Seattle District, for the Puget Sound Dredge Disposal Analysis and Puget Sound Estuary Programs. September 1986. 128 pp. + appendices.

Tetra Tech. 1987a. Commencement Bay Nearshore/Tideflats Feasibility Study: assessment of the potential success of source control. Draft Report. Prepared for the Washington State Department of Ecology. Tetra Tech, Inc., Bellevue, WA. 157 pp. + appendices.

Tetra Tech. 1987b. Commencement Bay Nearshore/Tideflats Feasibility Study: development of sediment criteria. Final Draft Report. Prepared for the Washington State Department of Ecology and U.S. Environmental Protection Agency. Tetra Tech, Inc., Bellevue, WA.

Tetra Tech. 1988a. Commencement Bay Nearshore/Tideflats Feasibility Study: assessment of alternatives. Final Report. Prepared for the Washington State Department of Ecology and U.S. Environmental Protection Agency. Tetra Tech, Inc., Bellevue, WA.

Tetra Tech 1988b. Elliott Bay Action Program: a storm drain monitoring approach. Draft report. Prepared for the Puget Sound Estuary Program, U.S. Environmental Protection Agency Region X. Tetra Tech, Inc., Bellevue, WA. 93 pp. + appendices.

Tetra Tech. 1988c. Elliott Bay Action Program: the relationship between source control and recovery of contaminated sediments in two problem areas. Draft Report. Prepared for the Puget Sound Estuary Program, U.S. Environmental Protection Agency Region X. Tetra Tech, Inc., Bellevue, WA. 66 pp. + appendices.

Tetra Tech 1988d. Phase I Remedial Investigation City Storm Drain Sediment Sampling and Analysis Plan for Harbor Island Seattle, WA. Draft Report. Prepared for Jacobs Engineering Group, Inc., Seattle, WA and U.S. Environmental Protection Agency Region X, Seattle, WA. Tetra Tech, Inc., Bellevue, WA.

Tetra Tech. In preparation. Elliott Bay Action Program: evaluation of potential contaminant sources. Prepared for the Puget Sound Estuary Program, U.S. Environmental Protection Agency Region X. Tetra Tech, Inc., Bellevue, WA.

Tomlinson, R.D., B.N. Bebee, A.A. Heyward, S.G. Munger, R.G. Swartz, S. Lazoff, D.E. Spyridakis, M.F. Shepard, R.M. Thom, K.K. Chew, and R.R. Whitney. 1980. Fate and effects of particulates discharged by combined sewers and storm drains. U.S. Environmental Protection Agency, Washington, DC.

Tomlinson, R.P., B.N. Bebee, and R.G. Swartz. 1976. Combined sewer overflow studies. Municipality of Metropolitan Seattle, Seattle, WA. 98 pp.

Truitt, C.L. 1986. The Duwamish Waterway Capping Demonstration Project: engineering analysis and results of physical monitoring. Technical Report D-86-2, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

U.S. Army Corps of Engineers. 1986a. Draft supplemental to U.S. Navy environmental impact statement carrier battle group Puget Sound region ship homeporting project. Technical Appendices. Vol. 1. U.S. Army Corps of Engineers, Seattle District, Seattle, WA.

U.S. Army Corps of Engineers. 1986b. Guidelines for selecting control and treatment options for contaminated dredged material requiring restrictions. Prepared for Puget Sound Dredged Disposal Analysis. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

U.S. Army Corps of Engineers. 1988. Draft technical appendix evaluation procedures Phase 1 (central Puget Sound). Prepared by Evaluation Procedures Work Group for Puget Sound Dredge Disposal Analysis. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

U.S. Environmental Protection Agency. 1982-1983. Organic analyses for Duwamish River surveys. Unpublished data.

U.S. Environmental Protection Agency. 1985a. Guidance on feasibility studies under CERCLA. U.S. EPA, Office of Emergency and Remedial Response, Washington, DC. 9 pp.

U.S. Environmental Protection Agency. 1985b. Covers for uncontrolled hazardous waste sites. EPA/540/2-85/002. U.S. EPA, Washington, DC.

U.S. Environmental Protection Agency. 1986a. Handbook for stabilization/-solidification of hazardous wastes. EPA/540/2-86/001. U.S. EPA, Washington, DC.

U.S. Environmental Protection Agency. 1986b. Mobile treatment technologies for Superfund wastes. EPA 540/2-86/003(f). U.S. EPA, Washington, DC.

U.S. Environmental Protection Agency. 22 October 1987. Personal Communication (computer print-out of CERCLIS V.2.0 List 1 - site location listing for King County retrieved from U.S. EPA Region X Superfund database). U.S. EPA Region X, Seattle, WA. 21 pp.

U.S. Environmental Protection Agency. 1987. Data requirements for selecting remedial action technology. EPA/600/2-87/001. U.S. EPA, Cincinnati, OH.

Yoshino, Z., K. Sato, H. Okajima, F. Kodama, S. Taguchi, R. Sudo, and M. Okada. 1985. Dewatering of bottom sediments. pp. 249-276. In: Management of Bottom Sediments Containing Toxic Substances, Proceedings of the 10th U.S./Japan Experts Meeting. T.R. Patin (ed). Water Resources Support Center, Fort Belvoir, VA.

APPENDIX A

DENNY WAY CSO PROBLEM AREA

SEDIMENT CONTAMINANT DATA

TABLE A-1. CONCENTRATION OF INORGANICS IN DENNY WAY CSO OFFSHORE SEDIMENTS
(MG/KG DRY WEIGHT = PPM)

Survey	Station	Sample	Rep	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper	Iron
PTI and Tetra Tech 1988	NS-01	NS-01		23.9	4.9		1.14	E104	251	29000
Malins et al. 1980	10041	10041					6.5		58.8	
Romberg et al. 1984	1406	1406			11.9				108.5	
	1512	1512			12.5				53.5	
	1603	1603			16.7				113	
	1606	1606			10.6				45.5	
	1612	1612			15				58	
	1706	1706			12.3				52	
	1810	1810			11.5				70	
	A060	A060		0.87	0.5	0.79	2.8	39	94	11000
	B060	B060		1.3	12	1.1	1.5	50	140	32000
	C060	C060		U0.03	44	0.89	1.5	51	61	24000
	S0032	S0032		0.45	9.3	0.33	0.86	52	49	18000
Romberg et al. 1987	BC-09	1					0.2		35	
	BC-33	2					0.6		60	
	BC-26	3					1.0		68	
	BC-19	4					1.1		73	
	BD-17	5					2.4		72	
	BC-25	6					1.1		72	
	BC-30	7					2.4		102	
	BC-22	8					2.0		109	
	BC-18	9					1.7		101	
	BC-16	10					2.3		92	
	BD-13	11					1.6		70	
	BD-10	12					1.9		86	
	BC-28	13					0.5		58	
	BC-32	14A					0.6		55	
	BC-23	15					0.5		42	
	BC-29	16					1.7		116	
	BC-21	17					2.6		132	
	BC-17	18					3.2		140	
	BD-15	19	01				2.8		212	
	BD-15	19	02				3.4		147	
	BD-15	19	Mean				3.1		179	
	BD-12	20					2.7		162	
	BD-09	21					2.3		112	
	BD-08	22					2.4		106	
	BD-07	23					2.3		94	
	BC-24	24					1.9		70	
	BC-31	25A					1.6		90	
	BC-27	26A					0.8		609	
	BD-16	27					3.2		264	
	BD-14	28					6.1		302	
	BD-18	30A					1.8		87	

TABLE A-1. (Continued)

Survey	Station	Sample	Rep	Lead	Manganese	Nickel	Selenium	Silver	Thallium	Zinc	Mercury
PTI and Tetra Tech 1988	NS-01	NS-01		217	E525	43.5	U0.11	E8.27		E158	E0.405
Malins 1980	10041	10041		74.3				3.8		97.8	1.1
Romberg et al. 1984	1406	1406		149.5						155	
	1512	1512		74						105	
	1603	1603		530						433.3	
	1606	1606		68.5						118	
	1612	1612		94						115	
	1706	1706		115						193.3	
	1810	1810		101						120	
	A060	A060		220	220	54	0.07	0.72	U0.007	210	0.71
	B060	B060		120	280	58	0.65	1.2	U0.015	140	U0.012
	C060	C060		110	290	63	0.02	0.89	U0.01	180	U0.007
	S0032	S0032		120	200	38	U0.2	1.9	U0.1	100	0.06
Romberg et al. 1987	BC-09	1		48						150	0.49
	BC-33	2		78						232	0.59
	BC-26	3		111						205	0.66
	BC-19	4		147						179	0.69
	BD-17	5		176						376	0.76
	BC-25	6		136						234	0.88
	BC-30	7		256						271	0.97
	BC-22	8		246						271	1.2
	BC-18	9		199						260	1.2
	BC-16	10		196						294	1.0
	BD-13	11		124						319	0.58
	BD-10	12		193						224	1.2
	BC-28	13		84						187	0.42
	BC-32	14A		97						143	0.47
	BC-23	15		95						165	0.23
	BC-29	16		241						241	0.57
	BC-21	17		398						273	1.8
	BC-17	18		398						374	0.99
	BD-15	19	01	340						248	2.2
	BD-15	19	02	407						307	1.1
	BD-15	19	Mean	373						277	1.7
	BD-12	20		267						257	1.1
	BD-09	21		304						268	1.7
	BD-08	22		148						262	1.1
	BD-07	23		260						258	0.98
	BC-24	24		149						188	0.74
	BC-31	25A		178						295	0.72
	BC-27	26A		109						170	0.44
	BD-16	27		350						445	0.70
	BD-14	28		478						472	2.2
	BD-18	30A		186						272	1.0

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-2. CONCENTRATION OF LOW MOLECULAR WEIGHT AROMATIC HYDROCARBONS IN DENNY WAY CSO OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station	Sample	Naphth-alene	Acenaph-thylene	Acenaph-thene	Fluorene	Phenan-threne	Anthra-cene
PTI and Tetra Tech 1988	NS-01	NS-01	U36	E1.7	E29	E15	E230	E50
Malins 1980	10041	10041	220	20	50	60	400	230
Romberg et al. 1984	A060	A060					E17	E17
	S0032	S0032	560		E51	430	5400	E2100
Romberg et al. 1987	BC-33	2	U80	U180	U100	U100	U270	U100
	BC-26	3	120	U180	U100	U100	580	210
	BD-17	5	140	U180	U100	130	1050	360
	BC-30	7	500	U180	120	C80	1900	580
	BC-16	10	170	U180	140	130	1200	400
	BD-10	12	110	U180	U100	U100	550	250
	BC-32	14A	110	U180	U100	U100	400	U100
	BC-23	15	U80	U180	U100	U100	450	240
	BC-29	16	130	U180	120	1500	1220	240
	BC-21	17	170	U180	200	U100	4400	1170
	BC-17	18	140	U180	U100	300	2280	1170
	BD-15	19	250	U180	170	640	3700	260
	BD-12	20	150	U180	130	150	1470	250
	BD-09	21	U80	U180	U100	160	800	210
	BD-08	22	120	U180	120	260	1810	2260
	CC-31	25A	U80	U180	140	U100	350	U100
	BC-27	26A	U80	U180	U100	U100	240	U100
	BD-16	27	1340	U180	12800	31500	98600	40700
	BD-14	28	350	U180	410	900	6400	3510
	BD-18	30A	U80	U180	U100	U100	550	200

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

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TABLE A-3. CONCENTRATION OF HIGH MOLECULAR WEIGHT AROMATIC HYDROCARBONS IN DENNY WAY CSO OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station	Sample	Fluor-anthene	Pyrene	Benzo(a)-anthracene	Chrysene	Benzo(b)-fluor-anthene	Benzo(k)-fluor-anthene	Benzo(a)-pyrene	Indeno-(1,2,3-cd)-pyrene	Dibenzo-(a,h)-anthra-cene	Benzo-(g,h,i)-perylene	Total Benzo-fluoran-thenes
PTI and Tetra Tech 1988	NS-01	NS-01	E440	E370	U2.1	U2.4	E94	E140	U2.6	U2.8	U4.3	U2.5	
Malins et al. 1980	10041	10041	490	640	310	360			260	150			
Romberg et al. 1984	A060	A060	72	53									
	B060	B060	E610	E610					E610				
	S0032	S0032	10000	12000	5400	8900			1300	640		720	
Romberg et al. 1987	BC-33	2	250	2620	190	360			360	U500	U500	U500	480
	BC-26	3	900	1000	610	1130			850	560	U500	720	1200
	BD-17	5	1590	1600	1070	U130			U130	610	U500	710	2400
	BC-30	7	2170	2020	1730	2400			1700	U500	U500	740	2400
	BC-16	10	1460	1830	1060	1400			1060	560	U500	U500	1680
	BD-10	12	880	890	1100	1200			850	610	U500	680	1500
	BC-32	14A	300	260	250	510			340	U500	U500	U500	520
	BC-23	15	430	370	370	590			780	U500	U500	U500	950
	BC-29	16	1730	1450	1060	1190			950	790	U500	620	1530
	BC-21	17	6800	5200	4000	5000			2400	1300	U500	1400	4500
	BC-17	18	3230	2750	2180	2860			1760	800	U500	800	2700
	BD-15	19	4800	4000	3200	4000			1740	700	U500	U500	3500
	BD-12	20	1900	2000	1200	1530			820	U500	U500	U500	1980
	BD-09	21	690	640	830	470			560	U500	U500	700	1120
	BD-08	22	2500	1840	2720	3140			870	800	U500	U500	2370
	BC-31	25A	460	440	290	480			280	U500	U500	U500	540
	BC-27	26A	240	240	150	280			170	U500	U500	U500	350
	BD-16	27	61500	36200	10700	26500			7500	U500	U500	U500	16400
	BD-14	28	6730	5000	3140	4000			1900	U500	U500	U500	3300
	BD-18	30A	660	630	390	680			490	U500	U500		930

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-4. CONCENTRATION OF PHENOLS IN DENNY WAY CSO OFFSHORE SEDIMENTS
(UG/KG DRY WEIGHT = PPB)

Survey	Station	Sample	Phenol	2-Methyl-phenol	4-Methyl-phenol	2,4-Dimethyl-phenol
PTI and Tetra Tech 1988	NS-01	NS-01	U6.0	U13	E37	U17
Romberg et al. 1987	BC-33	2	U80			
	BC-26	3	U80			
	BD-17	5	90			
	BC-30	7	U80			
	BC-16	10	U80			
	BD-10	12	U80			
	BC-32	14A	100			
	BC-23	15	U80			
	BC-29	16	580			
	BC-21	17	140			
	BC-17	18	U80			
	BD-15	19	190			
	BD-12	20	240			
	BD-09	21	130			
	BD-08	22	860			
	BC-31	25A	100			
	BC-27	26A	U80			
	BD-16	27	900			
	BD-14	28	1900			
	BD-18	30A	220			

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-5. CONCENTRATION OF SUBSTITUTED PHENOLS IN
DENNY WAY CSO OFFSHORE SEDIMENTS
(UG/KG DRY WEIGHT = PPB)

Survey	Station	Sample	2-Chloro-phenol	2,4-Dichloro-phenol	4-Chloro-3-methyl-phenol	2,4,6-Trichloro-phenol	2,4,5-Trichloro-phenol	Penta-chloro-phenol	2-Nitro-phenol
PTI and Tetra Tech 1988	NS-01	NS-01	U12	U33	U16	U31	U35	U2200	
Romberg et al. 1987	BC-33	2						U180	U120
	BC-26	3						U180	U120
	BD-17	5						790	380
	BC-30	7						U180	
	BD-08	22						560	

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

TABLE A-6. CONCENTRATION OF CHLORINATED AROMATIC HYDROCARBONS IN DENNY WAY CSO OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station	Sample	1,3-Dichloro-benzene	1,4-Dichloro-benzene	1,2-Dichloro-benzene	1,2,4-Trichloro-benzene	2-Chloro-naphtha-lene	Hexa-chloro-benzene
PTI and Tetra Tech 1988	NS-01	NS-01	U110	U110	U110	U180	U14	U93
Malins et al. 1980	10041	10041						0.3

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

TABLE A-7. CONCENTRATION OF CHLORINATED ALIPHATIC HYDROCARBONS IN DENNY WAY CSO OFFSHORE SEDIMENTS (UG/KG DRY WT = PPB)

Survey	Station	Sample	Hexachloro-butadiene
PTI and Tetra Tech 1988	NS-01	NS-01	U2200
Romberg et al. 1984	S0032	S0032	5.1

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

TABLE A-8. CONCENTRATION OF PHTHALATES IN
DENNY WAY CSO OFFSHORE SEDIMENTS
(UG/KG DRY WEIGHT = PPB)

Survey	Station	Sample	Dimethyl-phthalate	Di-n-butyl-phthalate	Butyl benzyl phthalate	Bis-(2-ethyl-hexyl)-phthalate	Di-n-octyl-phthalate
PTI and Tetra Tech 1988	NS-01	NS-01	E17		U2.3		U1.4
Romberg et al. 1984	A060	A060	E17				520
	B060	B060					23000
	S0032	S0032		770			13000
Romberg et al. 1987	BC-33	2	U80	U130	U130	1340	U130
	BC-26	3	U80	1670	220	1090	250
	BD-17	5	U80	1420	380	17300	1160
	BC-30	7	U80	790	650	15600	U130
	BC-16	10	U80	1000	500	400	U130
	BD-10	12	U80	700	250	2240	450
	BC-32	14A	U80	U130	U130	12100	U130
	BC-23	15	U80	U130	710	8800	U130
	BC-29	16	U80	400	410	22500	U130
	BC-21	17	U80	940	870	37000	U130
	BC-17	18	U80	1030	310	12400	U130
	BD-15	19	100	1020	680	18200	U130
	BD-12	20	U80	810	810	20800	U130
	BD-09	21	U80	590	230	4300	U130
	BD-08	22	U80	610	540	34100	U130
	BC-31	25A	U80	910	160	53700	U130
	BC-27	26A	U80	U130	U130	800	U130
	BD-16	27	180	340	1100	1200	U130
	BD-14	28	120	280	1830	400	U130
	BD-18	30A	U80	U130	520	500	U130

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-9. CONCENTRATION OF MISCELLANEOUS OXYGENATED COMPOUNDS
IN DENNY WAY CSO OFFSHORE SEDIMENTS
(UG/KG DRY WEIGHT = PPB)

Survey	Station	Sample	Isophorone	Benzyl alcohol	Benzoic acid	Dibenzo-furan	2-Methyl-naphthalene
PTI and Tetra Tech 1988	NS-01	NS-01	U22	U310	U110	E18	E7
Malins et al. 1980	10041	10041					90

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

E = Quantity listed is an estimated value.

TABLE A-10. CONCENTRATION OF PESTICIDES AND PCBS IN DENNY WAY CSO OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station	Sample	4,4'-DDE	4,4'-DDD	4,4'-DDT	Aldrin	Dieldrin	Alpha-BHC	Beta-BHC	Delta-BHC	Gamma-BHC (lindane)
PTI and Tetra Tech 1988	NS-01	NS-01	U4.8	U5.9	U5.3	U4.4	U4.1	U2.7	U6.0	U3.3	U3.1
Romberg et al. 1984	S0032	S0032	21	12	95						

Survey	Station	Sample	Chlordane	Endrin	Endrin-aldehyde	Hepta-chlor	Total PCBs
PTI and Tetra Tech 1988	NS-01	NS-01	U72	U5.5	U7.2	U4.1	U390
Malins et al. 1980	10041	10041					158
Romberg et al. 1984	1406	1406					1930
	1512	1512					1712
	1603	1603					2145
	1606	1606					2624
	1612	1612					1111
	1706	1706					479
	1810	1810					742
	A060	A060					8.1
	B060	B060					170
	C060	C060					2.3
	S0032	S0032					1448
Romberg et al. 1987	BC-33	2					260
	BC-26	3					410
	BD-17	5					510
	BC-30	7					770
	BC-16	10					580
	BD-10	12					670
	BC-32	14A					160
	BC-23	15					170
	BC-29	16					290
	BC-21	17					300
	BC-17	18					490
	BD-15	19					30
	BD-12	20					120
	BD-09	21					30
	BD-08	22					1510
	BC-31	25A					510
	BC-27	26A					220
	BD-16	27					300
	BD-14	28					1060
	BD-18	30A					930

Data Qualifiers:

U = Substance undetected at the method detection limit shown.

TABLE A-11. CONVENTIONAL PARAMETERS IN DENNY WAY CSO OFFSHORE SEDIMENTS

Survey	Station	Sample	Rep	Percent Total Solids	Percent Volatile Solids	Percent Total Organic Carbon	Percent Nitrogen	Oil and Grease (ppm)	Sulfide (ppm)
PTI and Tetra Tech 1988	NS-01	NS-01		83.03	2.18	E0.43	0.034	790	66
Romberg et al. 1987	BC-09	1		56.17	3.99				
	BC-33	2		51.95	5.23				
	BC-26	3		52.35	5.72				
	BC-19	4		55.42	5.53				
	BD-17	5		49.43	6.60				
	BC-25	6		48.33	7.78				
	BC-30	7		48.88	8.33				
	BC-22	8		56.04	5.18				
	BC-18	9		49.14	7.22				
	BC-16	10		50.40	6.83				
	BD-13	11		57.94	5.47				
	BD-10	12		49.88	6.08				
	BC-28	13		27.81	13.1				
	BC-32	14A		40.15	8.27				
	BC-23	15		62.77	5.13				
	BC-29	16		57.52	7.52				
	BC-29	16		57.52	7.52				
	BC-21	17		59.27	9.63				
	BC-17	18		54.83	8.81				
	BD-15	19	01	50.83	9.48				
	BD-15	19	02	48.36	11.2				
	BD-15	19	Mean	49.59	10.3				
	BD-12	20		51.02	7.41				
	BD-09	21		48.91	9.35				
	BD-08	22		54.53	7.38				
	BD-07	23		49.95	7.13				
	BC-24	24		54.86	5.90				
	BC-31	25A		43.39	7.91				
	BC-27	26A		59.57	4.57				
	BD-16	27		70.86	3.84				
	BD-14	28		41.02	14.5				
	BD-18	30A		38.61	8.63				

Data Qualifiers:

E = Quantity listed is an estimated value.

APPENDIX B

NORTH HARBOR ISLAND AREA

SEDIMENT CONTAMINANT DATA

TABLE B-1. CONCENTRATION OF INORGANICS IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS (MG/KG DRY WEIGHT = PPM)

Survey	Station	Antimony	Arsenic	Beryllium	Cadmium	Chromium	Copper
PTI and Tetra Tech 1988	NH-01	34.2	23.7		0.29	E97	65.5
	NH-02	110	22.8		0.52	E98	163
	NH-03	249	119		1.83	E50	2050
	WW-20	163	39.6		0.38	E67	167
U.S. EPA Region X 1982, 1983	E36		8.7		1		152
	E37		16.3		0.7		302
	E39	0.1	18		0.6		1220
	E4 82	0.9	48		0.3		150
	E4 83	14.5	560		1.6		2820
	E40	1.7	34.5		0.3		257
	E41		7.2		0.3		124
	E5		26		0.2		104
Gamponia et al. 1986	HE-02	1	21		0.34	41	110
	HE-01	2	110		1	94	440
	HE-03	3	300		1.6	190	2000
	HD-04	4	79		0.66	37	170
	HD-03	5	43		0.33	36	130
Malins et al. 1980	10016				5.7		90.2
Romberg et al. 1984	S0063	3.9	7.1	0.2	0.28	27	90
Stober and Chew 1984	U121		83.7	1.4	0.24	52.8	220

TABLE B-1. (CONTINUED)

Survey	Station	Iron	Lead	Manganese	Nickel	Mercury	Selenium
PTI and Tetra Tech 1988	NH-01	34200	61.3	E534	41.5	E0.223	U0.12
	NH-02	41000	113	E639	33.6	E0.565	0.3
	NH-03	74200	550	E1040	82.4	E10.5	0.49
	WW-20	40900	101	E680	22.7	E0.776	0.18
U.S. EPA Region X 1982, 1983	E36		80	164		0.316	0.3
	E37		966	235		0.925	0.4
	E39		281	766		0.852	0.2
	E4 82		93	134		0.7	
	E4 83		193	1460		7.67	
	E40		118	208		0.757	0.3
	E41		85	168		0.767	0.2
	E5		123	153		0.4	1.2
Gamponia et al. 1986	HE-02 1		87		16	0.55	
	HE-01 2		270		25	1.8	
	HE-03 3		730		47	14	
	HD-04 4		98		16	0.76	
	HD-03 5		100		13	0.87	
Malins et al. 1980	10016		60.8			1.4	
Romberg et al. 1984	S0063	14000	190	160	4.9	0.4	0.2
Stober and Chew 1984	U121		60.6	722	30.7	0.654	

TABLE B-1. (CONTINUED)

Survey	Station	Silver	Zinc
PTI and Tetra Tech 1988	NH-01	E0.24	E196
	NH-02	E0.52	E228
	NH-03	E1.02	E1300
	WW-20	E0.36	E259
U.S. EPA Region X 1982, 1983	E36	0.59	191
	E37	1.16	306
	E39	0.11	578
	E4 82	0.4	207
	E4 83	1.04	3205
	E40	0.42	395
	E41	0.43	140
	E5		136
Gamponia et al. 1986	HE-02 1		140
	HE-01 2		690
	HE-03 3		1900
	HD-04 4		250
	HD-03 5		200
Malins et al. 1980	10016	1.9	106
Romberg et al. 1984	S0063	0.16	84
Stober and Chew 1984	U121	0.2	659

TABLE B-2. CONCENTRATION OF LOW MOLECULAR WEIGHT AROMATIC HYDROCARBONS IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
PTI and Tetra Tech 1988	NH-01	E110	E110	E74	E100	E880	E460
	NH-02	E200	E160	E150	E260	1200	E660
	NH-03	E880	E230	E590	E920	E3700	E1900
	WW-20	E210	E75	E53	E79	E650	E240
U.S. EPA Region X 1982, 1983	E36	E270					
	E37						
	E39						
	E4 83	1300					
	E4 82						
	E40						
	E41						
	E5	E200					
Gamponia et al. 1986	HE-02 1	U0	U0	U0	L90	L850	L250
	HE-01 2	U0	U0	U0	U0	U0	U0
	HE-03 3	L1200	L490	U0	L700	L3500	L1300
	HD-04 4	U0	U0	U0	U0	L490	U0
	HD-03 5	L155	U0	U0	U0	L1100	L250
Malins et al. 1980	10016	610	10	210	210	1600	1200
Romberg et al. 1984	S0063		E47	950	1300	450	110
Stober and Chew 1984	U121	51	7		96	516	239

TABLE B-3. CONCENTRATION OF HIGH MOLECULAR AROMATIC HYDROCARBONS IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station	Fluor-anthene	Pyrene	Benzo-(a)-anthra-cene	Chrysene	Benzo-(B+K)-Fluoran-thenes
PTI and Tetra Tech 1988	NH-01	1800	2300	1300	2400	4500
	NH-02	E1700	1900	1100	2200	E2240
	NH-03	E4400	E9200	E3300	E4300	E11800
	WW-20	E930	1300	E520	E730	E1280
U.S. EPA Region X 1982, 1983	E36		13000			
	E37		13000			
	E39		7000			
	E4 83		120000			
	E4 82		1600			1700
	E40		7200			
	E41		1500			
	E5		1100			870
Gamponia et al. 1986	HE-02 1	L1100	L1700	L170	L380	L1100
	HE-01 2	L1500	L2300	L260	L500	L1600
	HE-03 3	L5500	L7500	L1500	L1900	L5000
	HD-04 4	L600	L730	U0	U0	L240
	HD-03 5	L2100	L1800	L230	L360	L900
Malins et al. 1980	10016	3200	2800	1400	900	2500
Romberg et al. 1984	S0063	200	200	180	550	2200
Stober and Chew 1984	U121	738	1252	472	952	570

TABLE B-3. (CONTINUED)

Survey	Station		Benzo-(a)-Pyrene	Indeno-(1,2,3-c,d)-Pyrene	Dibenzo-(a,h)-anthra-cene	Benzo-(g,h,i)pery-lene
PTI and Tetra Tech 1988	NH-01		E1000	E660	E200	E520
	NH-02		E820	E430	E160	E370
	NH-03		E3800	E5800	E2900	E4900
	WW-20		E490	E660	U123	E410
U.S. EPA Region X 1982, 1983	E36					
	E37					
	E39					
	E4	83				
	E4	82				
	E40					
	E41					
	E5					
Gamponia et al. 1986	HE-02	1	L550	L100	U0	L90
	HE-01	2	U0	U0	U0	L120
	HE-03	3	L10000	U0	U0	L750
	HD-04	4	U0	U0	U0	U0
	HD-03	5	L700	U0	U0	U0
Malins et al. 1980	10016		960	480		
Romberg et al. 1984	S0063		880	620	190	510
Stober and Chew 1984	U121		336	389	110	266

TABLE B-4. CONCENTRATION OF PHENOLS IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station	Phenol	4-methyl-phenol	2-methyl-phenol	2,4-dimethyl-phenol
PTI and Tetra Tech 1988	NH-01	U47	U76	U75	U20
	NH-02	U7.1	U19	U18	U13
	NH-03	E61	U8.6	U8.6	U6.9
	WW-20	U11	U29	U29	
U.S. EPA Region X 1982, 1983	E36				
	E37				
	E39				
	E4 82				
	E4 83				
	E40				
	E41				
	E5				
Gamponia et al. 1986	HE-02 1	L20			L140
	HE-01 2	U0			L210
	HE-03 3	U0			L193
	HD-04 4	U0			U0
	HD-03 5	U0			L140
Malins et al. 1980	10016				
Romberg et al. 1984	S0063	27			
Stober and Chew 1984	U121				

TABLE B-5. CONCENTRATION OF SUBSTITUTED PHENOLS IN NORTH HARBOR ISLAND SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station	2-chloro-phenol	2,4-di-chloro-phenol	4-chloro-3-methyl-phenol	2,4,6-tri-chloro-phenol	2,4,5-tri-chloro-phenol	penta-chloro-phenol
PTI and Tetra Tech 1988	NH-01	U67	U110	U26	U61	U55	E101
	NH-02	U16	U55	U28	U62	U48	U300
	NH-03	U7.9	U27	U9	U18	U40	U500
	WW-20	U26	U48	U22	U52	U52	U280
U.S. EPA Region X 1982, 1983	E36						
	E37						
	E39						
	E4 82						
	E4 83						
	E40						
	E41						
	E5						
Gamponia et al. 1986	HE-02 1				U0		L8.5
	HE-01 2			142	U0		U0
	HE-03 3			178	U0		L110
	HD-04 4				U0		U0
	HD-03 5				U0		U0
Malins et al. 1980	10016						
Romberg et al. 1984	S0063						
Stober and Chew 1984	U121						

TABLE B-6. CONCENTRATION OF CHLORINATED AROMATIC HYDROCARBONS IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station		1,3-dichloro-benzene	1,4-dichloro-benzene	1,2-dichloro-benzene	1,2,4-tri-chloro-benzene	2-chloro-naphtha-lene	hexa-chloro-benzene
PTI and Tetra Tech								
1988	NH-01		U120	U120	U120	U300	U19	U100
	NH-02		U140	U140	U140	U160	U16	U120
	NH-03		U190	U190	U190	U86	U7.6	U200
	WW-20		U140	U140	U140	U230	U17	U210
U.S. EPA Region X								
1982, 1983	E36							
	E37							
	E39							
	E4	82						
	E4	83						
	E40							
	E41							
	E5							
Gamponia et al.								
1986	HE-02	1	U0	U0	U0	U0		U0
	HE-01	2	U0	U0	U0	U0		U0
	HE-03	3	U0	U0	U0	U0		U0
	HD-04	4	U0	U0	U0	U0		U0
	HD-03	5	U0	U0	U0	U0		U0
Malins et al. 1980	10016							0.1
Romberg et al. 1984	S0063							
Stober and Chew 1984	U121							

TABLE B-7. CONCENTRATION OF CHLORINATED ALIPHATIC HYDROCARBONS IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT)

Survey	Station		hexa-chloro-ethane	hexa-chloro-butadiene
PTI and Tetra Tech 1988	NH-01			U2400
	NH-02			U3000
	NH-03			U670
	WW-20			U2800
U.S. EPA Region X 1982, 1983	E36			
	E37			
	E39			
	E4	82		
	E4	83		
	E40			
	E41			
	E5			
Gamponia et al. 1986	HE-02	1	U0	U0
	HE-01	2	U0	U0
	HE-03	3	U0	U0
	HD-04	4	U0	U0
	HD-03	5	U0	U0
Malins et al. 1980	10016			
Romberg et al. 1984	S0063			
Stober and Chew 1984	U121			

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TABLE B-8. CONCENTRATION OF PHTHALATES IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT = PPB)

Survey	Station		di-methyl-phthalate	di-ethyl-phthalate	di-n-butyl-phthalate	butyl-benzyl-phthalate	bis-(2-ethyl-hexyl)-phthalate	di-n-octyl-phthalate
PTI and Tetra Tech 1988	NH-01		E30			E54		E35
	NH-02		U11			B6.1		E52
	NH-03		U6.1			E68		B1.8
	WW-20		E11			B11		E76
U.S. EPA Region X 1982, 1983	E36							
	E37							
	E39							
	E4	82						
	E4	83						
	E40							
	E41							
	E5							
Gamponia et al. 1986	HE-02	1	U0	U0	L180	U0		U0
	HE-01	2	U0	U0	U0	U0	500	U0
	HE-03	3	U0	U0	L180	U0	1400	U0
	HD-04	4	U0	U0	U0	U0		U0
	HD-03	5	U0	U0	U0	U0		U0
Malins et al. 1980	10016							
Romberg et al. 1984	S0063				230	E3.1		620
Stober and Chew 1984	U121				88			

TABLE B-9. CONCENTRATION OF MISCELLANEOUS OXYGENATED COMPOUNDS
IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS
(UG/KG DRY WEIGHT = PPB)

Survey	Station	iso-phorone	benzyl alcohol	benzoic acid	dibenzo-furan	2-methyl-naphtha-lene
PTI and Tetra Tech 1988	NH-01	U200	U350	U182	E44	E30
	NH-02	U20	U430	U100	E94	E72
	NH-03	U7.7	U560	U55	E480	E220
	WW-20	U14	U400	U140	E40	E38
U.S. EPA Region X 1982, 1983	E36					
	E37					
	E39					
	E4 82					
	E4 83	2300				
	E40					
	E41					
	E5	U200				
Gamponia et al. 1986	HE-02 1					
	HE-01 2					
	HE-03 3					
	HD-04 4	662				
	HD-03 5					
Malins et al. 1980	10016					250
Romberg et al. 1984	S0063					
Stober and Chew 1984	U121					

TABLE B-10. CONCENTRATIONS OF PESTICIDES AND PCBS IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS (UG/KG DRY WEIGHT)

Survey	Station	4,4'-DDE	4,4'-DDD	4,4'-DDT	aldrin	dieldrin	alpha-HCH	beta-HCH
PTI and Tetra Tech 1988	NH-01	U3.9	U5.6	U4.7	U3.4	U4.8	U2.0	U5.0
	NH-02	U4.0	U5.9	U4.9	U3.6	U5.0	U2.1	U5.2
	NH-03	U20	120	U22	U18	U17	U11	U24
	WW-20	U4.0	U5.8	U4.9	U3.6	U5.0	U2.1	U5.2
U.S. EPA Region X 1982, 1983	E36							
	E37							
	E39							
	E4 82							
	E4 83							
	E40							
	E41							
	E5							
Gamponia et al. 1986	HE-02 1	U0	U0	U0				
	HE-01 2	U0	U0	U0				
	HE-03 3	U0	U0	U0				
	HD-04 4	U0	U0	U0				
	HD-03 5	U0	U0	U0				
Malins et al. 1980	10016							
Romberg et al. 1984	S0083	4.1	E0.14					
Stober and Chew 1984	U121	2.5						

TABLE B-10. (CONTINUED)

Survey	Station	delta-HCH	gamma-HCH (lindane)	chlordane	endrin	endrin-aldehyde	hepta-chlor	toxa-phene
PTI and Tetra Tech 1988	NH-01	U2.6	U2.3	U61	U4.8	U6.5	U3.2	
	NH-02	U2.8	U2.4	U6.4	U5.1	U6.8	U3.3	
	NH-03	U13	U13	U290	U23	U29	U17	
	WW-20	U2.7	U2.4	U63	U5.0	U6.7	U3.3	
U.S. EPA Region X 1982, 1983	E36							
	E37							
	E39							200
	E4 82							
	E4 83							200
	E40							200
	E41							200
	E5							
Gamponia et al. 1986	HE-02 1							
	HE-01 2							
	HE-03 3							
	HD-04 4							
	HD-03 5							
Malins et al. 1980	10016							
Romberg et al. 1984	S0063							
Stober and Chew 1984	U121							

TABLE B-10. (CONTINUED)

Survey	Station	Arochlor 1016	Arochlor 1221	Arochlor 1232	Arochlor 1242	Arochlor 1248	Arochlor 1254	Arochlor 1260
PTI and Tetra Tech 1988	NH-01							
	NH-02							
	NH-03							
	WW-20							
U.S. EPA Region X 1982, 1983	E36						E100	E1200
	E37							E1400
	E39	100					E100	720
	E4 82				E200			E200
	E4 83	100					E200	3700
	E40	100					E100	E200
	E41	100						E250
	E5				260			E200
Gamponia et al. 1986	HE-02 1	U0	U0	U0	L50	L50	L1700	L500
	HE-01 2	U0	U0	U0	L25	L25	L180	L150
	HE-03 3	U0	U0	U0	L420	L420	L2300	L900
	HD-04 4	U0	U0	U0	U0	U0	L1400	L80
	HD-03 5	U0	U0	U0	L75	L75	L130	L37
Malins et al. 1980	10016							
Romberg et al. 1984	S0063							
Stober and Chew 1984	U121							

TABLE B-10. (CONTINUED)

Survey	Station		total PCBs
PTI and Tetra Tech 1988	NH-01		E160
	NH-02		E190
	NH-03		E3300
	WW-20		E160
U.S. EPA Region X 1982, 1983	E36		E1300
	E37		E1500
	E39		E920
	E4	82	E400
	E4	83	E4000
	E40		E400
	E41		E350
	E5		E460
Gamponia et al. 1986	HE-02	1	L2300
	HE-01	2	L480
	HE-03	3	L4000
	HD-04	4	L1500
	HD-03	5	L320
Malins et al. 1980	10016		171
Romberg et al. 1984	S0063		466
Stober and Chew 1984	U121		198

TABLE B-11. CONVENTIONAL PARAMETERS IN NORTH HARBOR ISLAND OFFSHORE SEDIMENTS

Survey	Station	percent total solids	percent total volatile solids	percent total organic carbon	percent nitrogen	oil and grease (ppm)	sulfide (ppm)
PTI and Tetra Tech 1988	NH-01	71.99	2.93	E0.99	0.057	248	73
	NH-02	60.40	5.82	E1.78	0.09	567	107
	NH-03	41.18	7.25	E3.01	0.15	4089	359
	WW-20	63.77	3.93	E1.07	0.073	286	35
Stober and Chew 1984	U121	62.2	3.17	0.850	0.057	142	

APPENDIX C

SEDIMENT REMEDIAL ALTERNATIVE EVALUATION CRITERIA

SEDIMENT REMEDIAL ALTERNATIVE EVALUATION CRITERIA

Requirements of Comprehensive Environmental Response Compensation and Liability Act (CERCLA), the National Contingency Plan (NCP), and Superfund Amendments and Reauthorization Act (SARA) were used as guidance for development of evaluation criteria applicable to sediment remediation in Elliott Bay. Final guidance has not been provided by U.S. EPA on the procedures for evaluating remedial alternatives at Superfund sites under SARA. However, the draft guidance document for conducting feasibility studies in accordance with CERCLA/SARA has been incorporated into the evaluation process for Commencement Bay (U.S. EPA 1987b). In addition, categories of criteria specified in CERCLA guidance documents (e.g., U.S. EPA 1985e) were modified on an interim basis by U.S. EPA (1986d) and Porter (1987) to include new requirements under SARA [e.g., compliance with all applicable or relevant and appropriate requirements (ARARs) and preference for permanent solutions or treatments]. Although the process of sediment remediation in Elliott Bay problem areas will not be conducted under CERCLA regulations, the criteria for sediment remediation at the Commencement Bay Nearshore/Tideflats Superfund site are used here for defining pertinent regulations. Criteria applicable to Superfund remedial actions only are also noted.

Effectiveness, implementability, and cost criteria are defined in Sections 6.1, 6.2, and 6.3, respectively. Section 6.2 is substantially longer than the other sections, primarily because the set of applicable or relevant and appropriate requirements (ARARs) discussed under institutional feasibility is large and complex. Section 6.4 presents the framework for selecting the preferred sediment remedial alternative. By definition, this alternative must effectively meet the objectives of the Elliott Bay sediment remediation effort. The intent of recent guidance for CERCLA sites is to provide permanent solutions that are consistent with ARARs. One of the objectives for sediment remedial alternatives in Elliott Bay is to provide permanent solutions. Any remedial actions in Elliott Bay should also meet the objective of compliance with ARARs. The selection process is complicated by technical and institutional uncertainties and by tradeoffs among alternatives. The evaluations presented are based on the best available information. The relative significance of these uncertainties affects the final standing of the various alternatives. The tradeoffs that emerge in comparing the alternatives are also considered in the selection process. The final selection and implementation of the preferred alternative for each problem area may be modified to reflect availability of existing technology (e.g., availability of specialized dredge equipment), and refinements to the chemical database (e.g., core data for defining the depths of sediment contamination).

EFFECTIVENESS CRITERIA

The purpose of this section is to identify and define four effectiveness criteria: short-term protectiveness; timeliness; long-term protectiveness; and reductions in contaminant toxicity, mobility, or volume.

Short-Term Protectiveness

Short-term protectiveness is the predicted ability of the candidate sediment remedial alternative to minimize public health and environmental risks caused by exposure to contaminants during the implementation phase. The analysis identifies potential hazards associated with implementation and corresponding control measures. The evaluation of candidate sediment remedial alternatives based on short-term protectiveness includes the following considerations:

- Community protection during implementation - Potential public health risks due to implementing the alternative, including additional hazards due to the action itself. This evaluation includes a general assessment of potential hazards to public health associated with excavation, transfer/transport, treatment, and disposal of the contaminated sediment. Potential routes of exposure and targets are also considered.

- Worker protection during implementation - Potential occupational hazards due to implementing the alternative, including hazards associated with exposure of sediments during excavation, transfer/transport, treatment, and disposal. This evaluation includes both physical and chemical hazards associated with each process option, the degree of specialized safety training required for implementation, and an informal assessment of the potential hazards posed by a major worker exposure incident.

- Environmental protection during implementation - Nature and magnitude of potential environmental impacts associated with implementing the alternative. This evaluation includes identification of the environment at risk and review of the potential impacts associated with system failures during implementation.

Timeliness

Timeliness refers to the estimated time required for the candidate alternative to meet remedial objectives, that is, effect mitigation and achieve results based on observed biological effects. This evaluation includes an assessment of the time required for the following activities:

- Demonstration of feasibility of unproven technologies

- Modification of existing technologies to site-specific conditions

- Development of treatment or disposal facilities not currently in existence

- Implementation of sediment remediation, including treatment and disposal as necessary.

Implementation of effective source control is integral to the success of sediment remediation. Source controls must be implemented prior to or in conjunction with sediment remedial actions to assure maintenance of environmentally acceptable conditions. A revised action plan that identifies corrective actions for Elliott Bay problem areas is being developed (Tetra Tech in preparation).

Long-Term Protectiveness

Long-term protectiveness is the predicted ability of the candidate sediment remedial alternative to minimize potential hazards in both the problem areas and the ultimate disposal sites after the objectives of the alternative have been met. Effectiveness of the engineering and institutional controls available to manage risk (U.S. EPA 1987b) are especially important. This analysis includes an assessment of hazards associated with disposal of untreated waste or residuals resulting from treatment options. The analysis also assesses hazards due to potential failure of the technical components of the alternative (e.g., containment structures, treatment systems). The evaluation of candidate sediment remedial alternatives based on evaluation of long-term protectiveness includes the following considerations:

- Long-term reliability of containment facilities - Permanence in remediating the observed adverse environmental effects and in providing a final solution for the isolation, treatment, and disposal of contaminated sediments. The analysis estimates the magnitude and nature of the hazards due to potential failure of the protective components of the system, identifies the components most susceptible to failure, and assesses the engineering and institutional controls required to ensure system reliability. Population and environment at risk are identified.

- Protection of public health - Long-term ability to reduce public health hazards associated with the contaminated sediments within the disposal sites or residual contamination in problem areas. This evaluation includes an assessment of how the subject alternative achieves protection over time, how site hazards are permanently reduced, and how treatment or disposal processes impact long-term health hazards. This evaluation requires estimates of the feasibility of source control.

- Protection of the environment - Potential long-term environmental impacts associated with implementation, based on system reliability and associated long-term hazards. This evaluation includes identification of the environment and media at risk and the potential sensitivity of the environment to system failures (including failure to perform to prescribed specifications). This evaluation also requires an assessment of the effectiveness of system performance monitoring.

Reductions in Toxicity, Mobility, or Volume

This criterion addresses the statutory preference for using treatment technologies to reduce the principal threats posed by contaminants in the problem areas (U.S. EPA 1987b) as opposed to protection achieved through prevention of exposure. This analysis requires that volume be addressed separately from toxicity or mobility, because some of the treatment or removal process options can increase volumes (e.g., solidification, hydraulic dredging). For problem areas containing mixed wastes (e.g., organic and inorganic contaminants), the portion of the waste subject to treatment must be delineated. The reduction in the threat posed by the contaminants may be achieved through destruction of toxic contaminants (e.g., incineration), reduction of the total mass of toxic contaminants (e.g., chemical oxidation), irreversible reduction in contaminant mobility (e.g., solidification), or reduction of total volume of contaminants (e.g., solvent extraction). The degree to which treatment processes are irreversible, the type and quantity of residuals remaining following treatment, and the methods for managing residuals are considered.

The evaluation under this criterion focuses on the treatment processes that are employed and the contaminants they have been developed to address. The estimated efficiency of the treatment process is considered based on the problem chemicals present. The percentage reduction in toxicity, mobility, or volume can only be quantified following the completion of bench-scale testing of problem sediments. Recent U.S. EPA guidance further suggests that alternatives be developed that use permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable. Based on the nature and concentration of the contaminants in the sediments of the eleven problem areas, resource recovery is not expected to be practical.

IMPLEMENTABILITY CRITERIA

The purpose of this section is to identify and define three general implementability criteria: technical feasibility, institutional feasibility, and availability.

Technical Feasibility

Technical feasibility is the ability of the candidate sediment remedial alternative to be fully implemented based on site-specific chemical and physical features as well as general construction and engineering constraints. The evaluation of technical feasibility focuses on implementation, maintenance, and monitoring. The evaluation of candidate sediment remedial alternatives based on technical feasibility includes the following considerations:

- Feasibility and reliability of process options - Feasibility of constructing the necessary components of the remedial alternatives, and reliability of the corresponding process options. This evaluation includes a qualitative estimate of hazards due to system failure at any point in the remediation process, and may include an evaluation of the effectiveness of contingency plans. The ability of a technology to meet specified process efficiencies or performance goals is also considered.

- Implementation of monitoring programs - Ability to track performance of the candidate alternative in meeting the remedial objectives. This evaluation involves estimating confidence in early detection of problems and identifying potential exposures (public health and environment) caused by inability to detect system failures. This evaluation also requires a determination of whether migration pathways are sufficiently well-defined to be adequately monitored.

- Implementation of O&M - Feasibility and time required to implement an O&M program to ensure the maximum reliability and performance of the system.

<u>Institutional Feasibility</u>

Institutional feasibility is the ability of the candidate sediment remedial alternative to meet the intent of all applicable criteria, regulations, and permitting requirements. The evaluation of the candidate sediment remedial alternatives based on institutional feasibility includes the following considerations:

- Approval of relevant agencies - Feasibility of obtaining necessary agency approvals, including time and activities required. Although CERCLA actions are exempt from permit requirements under SARA, this evaluation addresses the need for, and feasibility of, obtaining concurrence from appropriate agencies on whether the candidate alternative will meet the substantive aspects of the permit requirements.

The compliance of the subject alternative with advisories and guidance for similar projects in similar environmental settings is also considered.

- Compliance with ARARs - Compliance of the subject alternative with the regulatory framework governing activities related to the problem area-specific environmental setting, protection of public health, and activities required to implement the remedial action and associated process options. This evaluation focuses on the approach to handling and treatment of contaminated dredge material, including disposal, as required by the alternative.

The following detailed discussion is provided to identify applicable or relevant and appropriate requirements that must be considered in evaluating the alternatives.

Compliance with ARARs--

The purpose of this section is to identify ARARs in terms of their importance in assessing candidate alternatives. ARARs are critical in the selection of appropriate remedies and will influence the implementation of remedial alternatives in individual problem areas. Because several actions such as dredging, dredge water management, and dredged material disposal are common to more than one candidate alternative, the discussion is organized by functional activity rather than remedial alternative, as follows:

- No action

- Institutional controls

- Dredging

- Treatment of contaminated sediments

- Disposal of uncontaminated and contaminated sediments, capping material, and treatment residues.

ARARs of federal and state government and Indian tribes must be considered during remediation under CERCLA and SARA (40 CFR Part 300). These ARARs are also pertinent to remedial activities which are not conducted under CERCLA and SARA. Although local ordinances are not specified as ARARs, they are considered in the selection of alternatives. Section 121 (J)(2)(A) of SARA incorporates the CERCLA Compliance Policy specifying that remedial actions meet promulgated requirements, criteria, or limitations that are potentially applicable or relevant and appropriate. The policy further states that other standards, criteria, advisories, and guidance that may be useful in developing remedies are to be considered. For a non CERCLA/SARA action, federal, state, and local government and Indian tribe regulations must also be considered.

For CERCLA sites, Porter (1987) differentiates between requirements that are applicable, and requirements that are relevant and appropriate:

- Applicable requirements consist of substantive environmental protection requirements (e.g., standards for cleanup or control) promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site (e.g., water quality criteria, air emissions criteria, state hazardous waste regulations)

- Relevant and appropriate requirements consist of substantive requirements promulgated under federal or state law that, while not applicable, are sufficiently similar to applicable requirements that their use is well suited to a particular site (e.g., PSDDA guidance).

If components of a candidate remedial alternative fall under the jurisdiction of a given ARAR, that ARAR is deemed applicable. Jurisdictional requirements include the following:

- Substances covered
- Time period covered
- Types of facilities covered
- Persons covered
- Actions covered
- Areas covered.

A requirement may be relevant and appropriate even if it is not applicable. In general, a requirement can be considered relevant and appropriate if the situation at the site is sufficiently similar to a problem that the requirement is designed to address. This determination relies heavily on professional judgment, using the following factors to compare the site conditions to the requirement in question:

- Similarity of goals and objectives of the requirement and the remedial alternative
- Environmental media and substances regulated and targeted for remediation
- Action or activity regulated and considered for remediation
- Type of physical location, structure, and facility regulated and considered for remediation
- Resource use or potential use.

Federal, state, and local permits will be required for removal or remedial actions. Substantive (but not procedural or administrative) requirements of permit applications are relevant and appropriate for removal and remedial actions. The transfer of hazardous or contaminated material is allowed only if there is a facility operating in compliance with RCRA, TSCA, or other federal laws, and all applicable state and local requirements.

ARARs can be classified as chemical-specific, location-specific, or action-specific. <u>Chemical-specific ARARs</u> are health-based or risk-based concentrations or ranges of concentrations in environmental media for specific chemicals. Examples of chemical-specific ARARs are federal water quality criteria (WQC), air quality standards (federal, state, and local), and maximum contaminant levels [MCL, or MCL goals (MCLG)] set by the Safe Drinking Water Act (SDWA). If a chemical has more than one ARAR, the most stringent value should be used.

<u>Location-specific ARARs</u> may set restrictions on remedial activities based on the characteristics of the environment in the vicinity of the site. Examples of location-specific ARARs include the Coastal Zone Management Act (CZMA), Executive Orders for floodplain and wetland protection, and regulations to protect sites of archaeological and historical value.

<u>Action-specific ARARs</u> may set restrictions based directly on the nature of a remedial alternative. Examples of action-specific ARARs are RCRA design and monitoring requirements for closure and post-closure of disposal sites, and Clean Water Act requirements for dredging and dredged material disposal.

Other standards, criteria, advisories, and guidance that may be useful in developing remedial action alternatives include: local ordinances, guidelines, and advisories such as City of Seattle shoreline and land use plans; PSDDA guidelines for the handling and disposal of dredged material; and carcinogenic potency factors and reference doses established by U.S. EPA for use in developing criteria such as MCLs. These factors can also be classified as chemical-specific, action-specific, or location-specific.

The remainder of this section is organized by type of ARAR (i.e., chemical-, location-, or action-specific). For each ARAR type, a selected list of potential ARARs is developed; and for each ARAR, a determination is made about whether it is applicable, or relevant and appropriate.

Identification of Potential Chemical-Specific ARARs--For dredging and dredged material disposal, chemical-specific ARARs issued at the federal level that are potentially applicable include MCLs and MCLGs under RCRA and SDWA, and ambient water quality criteria. RCRA incinerator regulations include a process for establishing chemical-specific emission limitations for principal organic hazardous constituents (POHCs). In addition, U.S. EPA has proposed regulations to limit emissions from boilers utilizing contaminated materials as feedstock. MCLs are enforceable drinking water standards developed for public drinking water supplies. MCLs are based primarily on health considerations, with some allowance for cost and feasibility. MCLGs are developed under SDWA as chemical-specific health goals and are used to set MCLs. MCLGs are set at levels where there are no known or anticipated health effects, and include a safety margin. Federal ambient water quality criteria are based on laboratory bioassays and are designed for the protection of aquatic life. Under Section 121 of SARA, remedial actions require a level or standard of control which at least attains MCLGs or water quality criteria where such goals are deemed to be relevant and appropriate. For remedial actions in Elliott Bay, a level or standard of control which attains MCLGs or water quality criteria will also be relevant and appropriate.

Other potential federal ARARs include ambient air quality standards specified by the Clean Air Act and standards specified by the federal Occupational Safety and Health Act (OSHA). The Food and Drug Administration (FDA) has developed limited criteria for maximum levels of hazardous compounds in fish tissue. These criteria exist for PCBs (2.0 mg/kg) and mercury (1.0 mg/kg). The federal Clean Air Act specifies standards for suspended particulates and a limited number of chemicals. Under OSHA, the National Institute for Occupational Safety and Health (NIOSH) develops permissible exposure limits (PELs) and other enforceable exposure guidelines for selected hazardous chemicals.

At the state level, potential chemical-specific ARARs include air emission standards and requirements for new sources including Ecology's Toxic Air Guidelines. Requirements have also been promulgated by the Washington Industrial Safety and Health Act (WISHA) for workers exposed to hazardous chemicals.

At the regional level, potential chemical-specific ARARs include permit requirements and emissions standards of the PSAPCA and interim criteria for the disposal of dredged material in Puget Sound established by the PSDDA. PSAPCA has generally adopted and enforces federal clean air standards (although in some cases, regional standards are more restrictive). However, PSAPCA can, and has, developed chemical-specific standards on a case-by-case basis.

Other chemical specific information which is issued at the federal level includes carcinogenic potency factors (for carcinogens) and reference doses (for non-carcinogens). Carcinogenic potency factors and reference doses relate to sediment remedial activities through the development of human health risks based on various exposure pathways (e.g., consumption of seafood or ingestion of groundwater). Chemical-specific limits derived from exposure estimates may be considered. At the regional level, PSDDA interim guidelines for the disposal of dredged material in Puget Sound are also based on defining potential problem sediments as determined by biological effects associated with observed chemical contamination. PSDDA interim disposal guidelines are not codified but have been applied and are presently being considered for adoption for standard use by regulatory agencies in Puget Sound.

Determination of Applicability or Relevance and Appropriateness--Federal ambient water quality criteria are directly applicable to alternatives involving dredging or the placement of dredged material or other material in marine waters. Federal water quality criteria and PSDDA criteria apply to the substances in question (dredged material), persons covered (any person), and actions covered (dredging). PSDDA criteria and procedures have not been codified but they satisfy the definition of ARARs because they have been generally accepted and will be uniformly applied by federal and state regulatory agencies. Applicability of these ARARs does not depend on the time period covered or the types of facilities involved. Federal water quality criteria and PSDDA criteria are also applicable to confinement alternatives because this alternative involves the disposal of uncontaminated material. Federal water quality criteria are applicable to nearshore disposal alternatives insofar as there is a potential for contaminants from the dredged material to reach the adjacent water (e.g., water quality criteria are appropriate for use during a post-remediation monitoring plan).

OSHA and WISHA requirements are applicable insofar as workers may be exposed to hazardous substances during the course of remediation. Federal clean air standards and PSAPCA standards are applicable to the extent that materials may be released to the atmosphere during remediation (e.g., volatilization of contaminants during nearshore and upland placement, or release of contaminants during incineration). RCRA and SDWA MCL and MCLGs are applicable to the alternatives involving disposal at either upland or nearshore if there is an aquifer for public drinking water sources that may be affected. These ARARs are relevant and appropriate primarily because they regulate groundwater concentrations of contaminants - a factor that will have to be considered (e.g., via post-remediation monitoring) at upland and nearshore dredged material disposal sites. MCL, MCLGs, and water quality criteria for drinking water are relevant and appropriate for situations where groundwater is or may be used for drinking water. Where a groundwater aquifer is not used as a drinking water supply, but is discharging to Elliott Bay, acute and chronic marine water quality criteria are relevant and appropriate.

Major chemical-specific ARARs for contaminated sediment remedial alternatives are listed in Table 8. Chemicals listed in Table 8 are among chemicals found in one or more problem areas.

Identification of Potential Location-Specific ARARs--Location-specific ARARs issued at the federal level that are potentially applicable include the Coastal Zone Management Act (CZMA); Clean Water Act; Marine Protection, Research, and Sanctuaries Act (MPRSA); and the Rivers and Harbors Appropriations Act. The CZMA established a program whereby coastal states can receive assistance in developing their own coastal zone management program. The State of Washington developed such a program under the CZMA, with the Shoreline Management Act (described below) effectively superceding the CZMA. The most important components of the Clean Water Act are Section 401 (state water quality certification for federally permitted activities), Section 402 (establishes the NPDES program), and Section 404 (establishes a permitting and permit review process for dredging and dredged material disposal). The most important component of the MPRSA is its provisions, requirements, and guidelines for ocean disposal. The Rivers and Harbors Appropriation Act in essence gives the U.S. Army Corps of Engineers authority to regulate any activities that may interfere with navigation (e.g., dredging and dredged material disposal).

At the state level, potential location-specific ARARs are the Shoreline Management Act, Washington Department of Natural Resources (DNR) guidelines and procedures for leasing submerged lands, the Toxics Control Act, and the Department of Fisheries hydraulics permit requirements, and Department of Game hydraulics permit requirements. Under the state Shoreline Management Act, the City of Seattle has prepared a Shoreline Master Program to regulate land use and construction within the coastal zone. As trustee over the submerged lands of the state, DNR manages all dredged material disposal sites via a submerged lands leasing program.

At the regional and local levels, potential location-specific criteria are limited to 1) the requirements, procedures and guidelines for open-water disposal specified by PSDDA and 2) land use requirements specified by the

City of Seattle in its shoreline plan and land use plan (for areas outside the coastal zone). PSDDA has developed procedures for evaluating the suitability of dredged material for open-water unconfined disposal, and procedures, guidelines, and criteria for establishing open-water sites for the unconfined disposal of dredged material. PSDDA and PSWQA are in the process of developing similar guidance for other disposal options, including conventional land and nearshore disposal and confined disposal.

Under the Shoreline Management Act, the City of Seattle issues (or denies) a shoreline substantial development permit for any project within 200 ft of ordinary high water, including designation of a dredged material disposal site. Application of Seattle land use regulations will vary depending on specific land use designations in problem areas. The offshore, nearshore, and upland (within 200 ft of ordinary high water) disposal of dredged material, and any other remedial alternative involving shoreline development (e.g., construction of dredged material treatment facilities) is subject to the specifications and guidelines set forth in the Seattle shoreline and land use plans.

Determination of Applicability or Relevance and Appropriateness--Based on the determining factors listed above, Sections 404 and 401 of the Clean Water Act and Section 10 of the Rivers and Harbors Appropriations Act (guidance provided in 40 CFR Part 230.10 and 33 CFR Parts 320-330) are applicable to all remedial alternatives involving dredging and disposal of dredged material in navigable waters. The CZMA is applicable to alternatives involving the disposal of material or construction of treatment facilities in the coastal zone.

MPRSA requirements for ocean disposal are relevant and appropriate to remedial alternatives involving the open-water disposal of dredged or capping material. The MPRSA establishes guidelines and requirements for siting ocean disposal sites and monitoring dumping activities therein.

Major location-specific ARARs for contaminated sediment remedial alternatives are listed in Table 9. Status as applicable or relevant and appropriate is also shown for the ARARs.

Identification of Potential Action-Specific ARARs--This section is organized according to the following categories of actions involving contaminated sediments: no action; institutional controls; dredging; treatment of dredged material; and placement, disposal, or discharge of treated dredged material and water (e.g., from dewatering, settling, and treatment), untreated dredged material, capping material, and treatment residues (e.g., filter cakes from water treatment operations).

No Action--The "implementation" of this alternative would result in the nonattainment of many ARARs, including the intent of the National Contingency Plan. For example, the NCP requires that selected remedies cost-effectively mitigate and minimize threats to and provide adequate protection of public health and welfare and the environment [40 CFR Part 300.68(i)]. Based on the analysis of toxic contamination in Elliott Bay (PTI and Tetra Tech 1988), this goal would not be accomplished.

Institutional Controls--Institutional controls minimize human health risks from hazardous substances primarily via mechanisms that prevent exposure to the substances. There are many types of possible institutional controls, including site fencing, posting of health advisories, and bans for the consumption of contaminated biota or groundwater. Site fencing may require boundary survey work and consideration of Seattle land use and permitting requirements. Posting of health advisories may require close coordination with the King County Health Department and consideration of their regulations and guidelines. Because of the limited effectiveness of institutional controls alone, this alternative will fail to satisfy the goals set forth by PSWQA to clean up Puget Sound. However, it is feasible and advisable to use some selected institutional controls in conjunction with other remedial alternatives.

Dredging Activities--Dredging technologies under consideration include hydraulic cutterhead, specialized hydraulic dredge, watertight bucket clamshell, and mud cat. Federal action-specific ARARs relating to dredging include the Clean Water Act (Sections 404 and 401), Rivers and Harbors Appropriations Act (Section 10), and MPRSA. There are no state ARARs that specifically regulate dredging. However, state water quality requirements (under Section 401 of the Clean Water Act) may be considered during dredging activity and may be considered an action-specific ARAR as well as a location-specific ARAR. The water quality considerations may involve the state Departments of Ecology, Natural Resources, Fisheries, and Game. The Departments of Fisheries and Game are involved by virtue of their mandate to consider the substantive aspects of requirements for a hydraulics permit for any project that may interfere with the natural flow of surface water. ARARs that specifically regulate dredging in the Elliott Bay area are addressed in the City of Seattle shoreline management plan.

The substantive aspects of requirements established by the Clean Water Act (including state water quality certification), and the Rivers and Harbors Appropriations Act are applicable to dredging actions on an action-specific basis because remedial dredging satisfies their jurisdictional requirements. Limitations on times of the year when dredging may occur are mandated by the Muckleshoot Indian Tribe and the Department of Fisheries. In general, dredging is not allowed between mid-March and June, or during the fall.

It is possible that the applicability, or relevance and appropriateness of specific requirements of dredging ARARs may vary by problem area and by dredging technology. For example, compliance with substantive aspects of Sections 404 and 401 of the Clean Water Act and state water quality requirements will be necessary for all dredging activities. However, specific restrictions may be imposed by some agencies under certain conditions (e.g., required use of a silt curtain by the Department of Fisheries or Game to avoid impacts to migrating anadromous fish).

The MPRSA does not provide requirements or guidelines for the testing of dredged material per se and is thus not an applicable ARAR. However, general guidelines for the testing of material for ocean disposal may be relevant and appropriate for remedial alternatives involving dredging.

Treatment Activities--Categories of treatment technologies under consideration include solidification/stabilization, chemical treatment, incineration, physical treatment, and land treatment. There are a variety of alternative treatment methods within each of these categories. The discussion of ARARs in this section focuses only on the above four categories.

Most ARARs for contaminated sediment treatment relate to the release or disposal of materials resulting from the treatment process. In addition, there may be releases to the atmosphere (e.g., from incineration), groundwater (e.g., from infiltration of effluent or leachate), and surface water (discharge of effluent). There may also be the need to dispose of materials such as filters contaminated during the treatment process (see next section entitled Availability).

Potential federal ARARs for waste treatment are currently limited to onsite incineration and land treatment. There are proposed standards for thermal treatment other than incinerators; for chemical, physical, and biological treatment other than tanks, surface impoundments, or land treatment units; and for the control of volatile organic emissions from air stripping operations. There are no potential state ARARs for specific candidate treatment technologies.

Dredge, Treatment, and Capping Material Disposal--Action-specific ARARs that pertain to the disposal of materials overlap somewhat with chemical-specific and location-specific ARARs. ARARs for the open-water or nearshore disposal of dredged material (treated or untreated) or capping material are analogous to location-specific (and to some extent, chemical-specific) ARARs discussed above. ARARs for the disposal of treated and untreated dredged material and capping material depend to a significant degree on contaminant concentrations. For example, some materials may not meet the PSDDA chemical-specific guidelines for open-water treatment, requiring either confined nearshore or upland disposal.

Current state and U.S. EPA policy requires that any untreated, contaminated dredge sediments be disposed of at a facility that is in compliance with state requirements, RCRA or Toxic Substance Control Act [TSCA (for PCB disposal)]. The requirements for handling and disposal of treated dredge material will depend on chemical analyses conducted following remediation.

Action-specific ARARs may also be invoked for the disposal of effluent from treatment processes. It is very unlikely that an effluent will be classified as a RCRA hazardous waste or a state Dangerous or Extremely Hazardous Waste. However in such a case, the potential ARARs discussed above would have to be evaluated. Depending on the results of bench-scale treatability studies, treatment wastewater may be discharged to surface water or a publicly owned treatment works (POTW) if applicable effluent guidelines can be achieved. Potential federal ARARs for such actions include requirements for testing and monitoring of Section 402 of the Clean Water Act and requirements for the discharge of effluent to a POTW. Potential state ARARs for the discharge of treatment wastewater include the following:

- Water pollution control and discharge standards that require treatment with known, available, and reasonable methods

- Regulations for the protection of upper aquifer zones that require protection of water quality to the extent practical

- The state waste discharge program for discharges of wastewater to groundwater

- Water pollution control regulations that provide for the use of water quality regulations at hazardous waste sites.

The ARARs discussed above are all applicable because their jurisdictional requirements are met by the candidate remedial alternatives.

Additional considerations relating to Elliott Bay remedial actions would include current PSDDA guidelines for the testing of dredged material prior to disposal. Disposal options for treated and untreated dredged material and capping material depend to a significant degree on contaminant concentrations. In addition, construction of treatment facilities may require consideration of the City of Seattle's land use plan, building codes, and grading and drainage ordinances. It is unlikely that disposal of untreated sediment will be allowed at a local municipal solid waste landfill or PSDDA open-water unconfined site due to liability issues associated with hazardous and dangerous wastes.

Major action-specific ARARs for contaminated sediment remedial alternatives are listed in Table 10. Status as applicable, or relevant and appropriate is also shown.

Availability

This evaluation criterion refers to the availability of the equipment and specialized expertise required to perform the candidate alternative as well as the availability of the necessary treatment, storage, or disposal capacity. Current stage of development (i.e., of the various technologies) and potential vs. current availability are also considered.

At present, the availability of upland disposal facilities within the vicinity of Elliott Bay and King County is uncertain. As discussed in the preliminary screening of alternatives (Section 4.0), several potential disposal sites within the area have been reviewed. However, no upland disposal sites have been established and approved for disposal of contaminated dredge material. It was assumed for the evaluation, however, that an upland disposal facility could be made available within the project area. It was assumed that agency approval, tribal acceptance, and public acceptance would be feasible. These assumptions are based on the need for some kind of disposal facility based in the project area, to provide reasonable transportation costs.

The availability of nearshore disposal facilities within the Elliott Bay area is virtually zero. Port of Seattle sites may be available for dredging projects initiated by the Port. However, planning and design of a nearshore facility for designation as a multi-user site is not anticipated.

The potential for offsite disposal of untreated contaminated dredge material has largely been dismissed because of inherent difficulties associated with dewatering and transport of marine sediment, and the associated costs of both transport and disposal. However, if treated sediment is determined to meet local, state, and federal criteria for designation as nonhazardous waste, the material could feasibly be placed in a sanitary landfill or used as an inert fill material. Concentrated residues that may be generated by implementation of one or more treatment alternatives will be dealt with in strict accordance with state and federal regulations, including disposal at a RCRA-approved treatment, storage, or disposal facility, as appropriate. The factors which must be considered for disposal in a sanitary landfill (i.e., increased traffic, moisture content), and the recent regional problems with designation of landfill sites would make disposal in a sanitary landfill difficult. The use of limited landfill capacity for the disposal of sediment, especially with solid waste disposal rates on the rise, would probably raise considerable public controversy.

COST CRITERIA

Order-of-magnitude costs were estimated for each combination of remedial alternative and problem area. Costs were grouped into the following categories:

- Construction and implementation - Costs for engineering design, development of specifications, dredging, transportation, treatment, intertidal habitat replacement, and disposal.

- Operation and maintenance - O&M costs associated with all post-disposal onsite activities, including monitoring. Engineering site inspections of containment structures, erosion control, drainage, repairs, and landscape upkeep are all aspects of O&M. The latter category includes refertilization, mowing, and general maintenance of site vegetation.

Monitoring activities are designed for both short- and long-term surveillance of containment structure or cap performance. In practice, activities should begin just prior to the disposal operation and remain intense for the first year, tapering off over the course of an assumed 30-yr program. In this manner, failure to initially contain sediment contaminants can be detected immediately. In addition, frequent monitoring after completion of the remedial action allows an assessment of the rate and extent of contaminant migration that can be expected to occur over the long term. Assuming that initial monitoring efforts confirm predicted rates of contaminant migration based on preimplementation bench-scale tests and modeling studies, it is reasonable to assume that the sampling frequency can be reduced over time. The lack of contaminant releases within approximately 1 yr of sediment disposal indicates that the level of monitoring can be reduced.

Cost estimates for specific items within each category were normalized to 1988, using an annual inflation rate of 6 percent. For yearly costs associated with monitoring, operation, and maintenance, the present worth was calculated using a 10 percent interest rate. A discussion of the estimation method, assumptions, and information sources used is presented in Appendix D of Tetra Tech (1988).

SELECTION OF PREFERRED ALTERNATIVES

The definition and selection of a preferred remedial alternative for the two high priority problem areas in the Elliott Bay study area is provided in Section 7.0. The selection of a preferred remedial alternative is based on the following characteristics:

- Protection of human health and the environment
- Attainment of federal and state public health and environment requirements
- Cost-effectiveness
- Use of permanent solutions and alternative treatment or recovery technologies to the maximum extent practicable.

Treatment is defined as those activities that permanently and significantly reduce the toxicity, mobility, or volume of the hazardous substances. Selection of permanent remedies that have not yet been implemented under similar circumstances are authorized under the law. It is further stated in SARA that remedies requiring offsite transport of untreated contaminant materials should be the least favored action where practicable treatment technologies are available.

The following process was used to identify the preferred alternative in each problem area. First effectiveness and implementability of candidate alternatives were summarized. Results are shown in Section 6.0 as oversized narrative tables. Next, the candidate alternatives were compared with one another. Results are shown as "evaluation summary" tables, with ratings of high, moderate or low in the eight major evaluation criteria. The rationale and method followed when assigning ratings are described below. The preferred alternatives were identified from these summary tables. This approach was developed to select one preferred remedial alternative with the broadest applicability for each of the Elliott Bay problem areas selected for assessment, but the process is complicated by the variable nature of both the contaminants and the environmental and operational features within the problem areas. For this reason a brief review and sensitivity analysis was conducted to identify other alternatives that may be suitable for sediments contaminated by a particular class of compounds (e.g., inorganic contaminants) or located within a specific environmental setting (e.g., intertidal areas). A discussion of this analysis is presented for each problem area, following description of the preferred alternative.

Short-Term Protectiveness

Community, worker, and environmental protection during implementation of the candidate alternative are evaluated under the short-term protectiveness criterion.

A candidate alternative rates high for short-term protectiveness if minimal risks to workers and the community during implementation are expected. Community exposure risks are expected to be low, as site controls can be readily implemented for all alternatives to minimize potential contact with contaminated dredge material. Worker exposure potential is lowest for alternatives in which contaminated sediments are left in place. Alternatives involving dredging increase worker exposure risks, but process controls, available personal protective equipment, and the relatively low level of hazard associated with CDM contact preserves a high rating for this aspect of an alternative. Environmental protection during implementation is highest when sensitive resource areas are not damaged or destroyed by the alternative. Environmental controls exist for most alternatives (e.g., silt curtains for dredging, emissions controls for incineration). However, short-term impacts are expected for loss of habitat due to dredging, capping, or disposal operations.

Moderate ratings were assigned to candidate alternatives involving effective remediation technologies with an increased potential for some adverse impacts, but where engineering and safety controls are feasible. In this case, a moderate to high risk of exposure to workers may be anticipated, but safety controls are adequate to significantly reduce the exposure potential. Process-related risks associated with treatment alternatives prolong exposure potential, and therefore generally reduce the short-term protectiveness rating. A moderate rating was also given to an effective technology that poses moderate risk to a low sensitivity environment and that involves risk control methods which are difficult or costly to implement.

Candidate sediment remedial alternatives received low ratings if they offer only minor overall benefits, with high probability of producing, or allowing significant environmental impacts, and where engineering and safety controls are not feasible. This rating was also assigned to candidate alternatives that pose a high risk to sensitive environments or populations, with inadequate mitigative controls or monitoring capabilities.

Timeliness

The comparison of the candidate alternatives for timeliness is based on their ability to mitigate observed biological impacts rapidly without compromising the integrity of the various process options. The time required to consider agency comments on all components of the remediation system, including treatment, storage, and disposal facilities was considered. In all cases, source control measures were assumed to be implemented rapidly and effectively to facilitate subsequent implementation of sediment remediation.

A high rating was assigned to alternatives that can be completed within 1-2 yr of implementation of adequate source controls. These alternatives would have to rely on currently available equipment and facilities, with minimal bench-scale or pilot testing required. Alternatives that produce immediate environmental benefits were also rated high.

Moderate ratings were assigned to candidate alternatives that can be implemented within 2-5 yr following implementation of adequate source control. These alternatives would generally require some testing and development of technologies because there has been little or no field application to date. Alternatives that must be modified because the sediments are of marine origin or that require lengthy review times for any aspect of the technology were also rated moderate.

Low ratings for timeliness were assigned to candidate alternatives that require greater than 5 yr to implement and complete. Included in this category are alternatives that require substantial treatability testing or where significant delays in development may be expected (e.g., determination of treatment feasibility, siting of a land treatment facility).

Long-Term Protectiveness

The comparison of candidate alternatives in terms of long-term protectiveness is based on their effectiveness in permanently mitigating the observed adverse biological impacts the sediment contaminants in Elliott Bay. Reliability, long-term risks and benefits, uncertainties remaining after implementation of the alternative environments or populations at risk, and the effectiveness of monitoring following remediation were all considered. Included in the comparison of long-term protectiveness are the criteria for reviewing future exposure potentials, reliability, and public health and environmental protection.

The candidate alternatives that rate high afford a high degree of post-remediation reliability and security and allow monitoring to be readily implemented. System failures will be detectable long before public health or environmental impacts occur. High ratings were also assigned to facilities that would cause minimal adverse impacts if any critical component failed, and to alternatives that permanently reduce public health and environmental risks.

Moderate ratings were given to alternatives that present a higher potential for future exposure, yet are readily monitored or amenable to engineering controls. This rating also applies to alternatives that are less reliable, yet present minimal risk of adverse impacts from system failures. Moderate ratings were assigned to alternatives that remove or isolate contaminants with minimal on- or offsite risks.

Low ratings for long-term protectiveness were assigned to alternatives involving significant risks after remediation. For alternatives with a high degree of uncertainty and where significant adverse public health or environmental impacts would be expected from system failures, low ratings were applied. Alternatives involving a high potential for future exposure, or a great uncertainty concerning monitoring, or contaminant fate and transport also received a low rating.

Reductions in Contaminant Toxicity, Mobility, or Volume

The comparison of candidate sediment remedial alternatives in terms of reductions in toxicity, mobility, or volume focuses on the extent to which an alternative results in the permanent destruction or detoxification of sediment contaminants. The permanent treatment of waste contaminants affords a higher level of overall effectiveness than does isolation (Porter 1987).

High ratings for reductions in contaminant toxicity, mobility, or volume were assigned to alternatives that result in significant and irreversible reductions with minimal residual material. High ratings were also assigned to alternatives that may be less effective in reducing overall residual mass yet generate residual materials that can be classified as nonhazardous waste.

Moderate ratings are applicable to alternatives that provide some degree of reduction in toxicity, mobility, or volume. This rating was applied to alternatives incorporating treatment technologies that generate significant quantities of less hazardous waste.

Low ratings apply to alternatives that lack a treatment element. All capping and dredge/disposal alternatives rank low because they isolate contaminated sediments without substantially affecting the contaminants themselves, although mobility is physically limited.

Technical Feasibility

Technical feasibility is based on implementability and the reliability of the process options that make up each alternative, as judged by past performance in similar applications, the importance of long-term O&M to success of the system, and the effectiveness of monitoring systems in tracking performance.

High ratings for technical feasibility were applied to alternatives that can be implemented with little bench- or pilot-scale testing and that incorporate highly reliable, proven procedures. High ratings are also applicable to alternatives that require minimal O&M or where O&M procedures are well established, effective, and not absolutely essential to the ongoing performance of the treatment or isolation process. For those alternatives where performance monitoring is focused and allows early detection of system failures, high ratings were also given.

Moderate ratings for technical feasibility are applicable to alternatives that appear to be technically feasible, yet require extensive testing or development prior to implementation. Moderate ratings were also applied to alternatives that require more extensive, routine maintenance using proven procedures. Where monitoring requirements are more extensive but the systems are estimated to be effective in detecting performance problems, moderate ratings are also appropriate.

Low ratings for technical feasibility apply to alternatives that involve highly uncertain implementability or technologies that are significantly constrained by site conditions. Low ratings were given to alternatives that require extensive O&M following remediation, and where intensive O&M is critical to system success. Where monitoring needs are extensive but not necessarily effective in detecting failures prior to the onset of public health or environmental impacts, low ratings were also assigned.

Institutional Feasibility

Institutional feasibility is based on the ability of alternatives to adequately address all applicable or relevant and appropriate regulations and other non-promulgated agency guidelines, advisories, and policy that require consideration. The comparison of alternatives includes an assessment of the likelihood that ARARs can be met and that other guidelines and criteria can be favorably addressed.

High ratings for institutional feasibility were applied to alternatives that comply with all ARARs as well as all relevant guidance and policy. Alternatives that are flexible in terms of timing and that incorporate components likely to be approved by the regulatory agencies were also rated high.

Moderate ratings apply to alternatives that meet ARARs and meet the intent of most relevant guidance. Moderate ratings also apply to alternatives likely to receive agency acceptance, albeit through negotiations.

Low ratings apply to alternatives that do not comply with ARARs and present problems with respect to agency policy and guidance that is probably non resolvable.

Availability

Availability is based on the accessibility of necessary equipment, specialized expertise, and disposal facilities. The highest ratings for availability were assigned to alternatives that use existing and readily accessible materials, facilities, and personnel. A high rating was also applied to alternatives that can use existing facilities to accommodate treated or altered contaminated sediments.

Moderate ratings were applied to alternatives involving technologies that are regarded as feasible but require adaptation to the site-specific conditions. This rating applies to alternatives incorporating technologies that require bench-scale or treatability testing to define design parameters.

Low ratings were applied to alternatives that rely totally on unproven technologies; on technologies that require personnel and equipment not currently available in the project area; or on the use of disposal or treatment facilities not currently available or planned, or that appear to entail a high degree of uncertainty in their development.

Cost

The comparative evaluation of cost-effectiveness among alternatives can only be conducted following the evaluation of the effectiveness and implementability factors. This process allows the overall effectiveness of each alternative to be assessed, based on the objectives for the Elliott Bay action program. These objectives include mitigation of observed biological impacts and long term protection of the environment and the public health. Evaluation of cost-effectiveness can then be made after a final alternative candidate (or candidates) has been selected which offers the best balance of predicted results. In conducting a cost comparison of final candidates, consideration must be given to the statutory goal of permanently and significantly reducing contaminant toxicity, mobility, or volume, because alternatives which involve feasible permanent solutions generally require additional capital funds for implementation.

APPENDIX D

METHOD FOR ESTIMATING COSTS

METHOD FOR ESTIMATING COSTS
ELLIOTT BAY EVALUATION OF SEDIMENT REMEDIAL ALTERNATIVES

Detailed cost estimates were prepared for each of the alternatives developed for remediation of Elliott Bay problem areas. These costs were adapted from the Commencement Bay Feasibility Study Draft Report (Tetra Tech 1988a). Materials and construction costs from historic sources were adjusted to 1988 values using a 4 percent inflationary factor. The following discussion concerns development of unit costs used in estimating overall project costs. The discussion is organized chronologically from initiation of the sediment refinement sampling program, dredging operations, treatment (where appropriate), intertidal mitigation, to disposal and subsequent monitoring. Table D-14 itemizes the unit costs for remedial technologies. All unit costs have been translated into dollar/yd^3 of sediment treated or disposed, except for the in situ capping alternative, which is estimated at dollar/yd^2 of contaminated sediment.

Sampling programs required to refine sediment volumes prior to remediation comply with the sampling requirements for dredged material disposal assessments recommended by U.S. Army Corps of Engineers (1988). Assuming that all sediments rank high in chemical concentrations, the core sample and frequency of chemical analyses recommended was one for every 4,000 yd^3 for sediments above 4-ft depth. Sediment core costs, including boat and crew time, are approximately $1,500 per core for 10-50 cores in a sampling event. Chemical analysis costs will vary with each problem area. However, a cost of $1,200 per sample for chemical analysis was estimated.

For dredging operations, hydraulic dredges with the cutterhead option and mechanical dredges with clamshell bucket were selected. Operating costs for the 500 yd^3/h cutterhead, including the hydraulic transport of dredge slurry for 2 mi by pipeline, was estimated to be $1.50/$yd^3$. Costs for using an additional pipeline booster to transfer sediments to an upland disposal site were approximately $0.50/yd^3. The 200 yd^3/h clamshell dredge operating costs were estimated to be $1.25/yd^3, which does not include transporting the dredge spoils to the disposal site. Barge transport costs for hauling sediment were estimated at $0.50/yd^3 for up to 5 mi transport (Morris, J., 18 November 1987, personal communication). Truck transport costs for 2 mi round trip at 2 loads/h were estimated at $2.01/yd^3 (Means 1988).

The treatment options specifically considered for sediment remedial alternatives were incineration, solvent extraction, biological land treatment, solidification, and chemical clarification of dredge water at nearshore and upland disposal sites. The low heating value of sediments translates into high thermal treatment costs. Thermal treatment costs for contaminated soils range from $150 to $500 per ton depending on the types of contaminants and heating value of the contaminated material. The cost includes site preparation, labor, equipment, utilities, mobilization, decontamination and demobilization. Assuming the operating cost of approximately $220/ton for a mobile rotary kiln incineration unit (U.S. EPA 1986), exclusive of mobilization and demobilization costs, and a sediment density of 1.35 ton/yd^3, the unit incineration costs were estimated to be $300/yd^3. A 10 percent mark up cost was applied for mobilization and demobilization for all remedial activities.

The unit cost for solvent extraction is estimated to be $120/yd^3 (Austin, D., 22 January 1988, personal communication). For the land treatment option, a $100,000 treatability study was assumed. It was also assumed that a single 1 ft thick application of dredged sediment would be made. Costs for solidification were estimated to be $25/yd^3 of dredged sediment, assuming the solidification agent would be a cement/pozzolanic material (Conner, J., 18 November 1987, personal communication). Chemical clarification of hydraulically dredged sediment because of the low solids content was assumed. Chemical clarification operating costs were estimated at $0.35/yd^3 for hydraulically dredged sediment (Schroeder, P., 18 November 1987 personal communication). Construction costs for clarification were assumed to be 25 percent of settling basin construction costs, which accounts for an additional berm for the secondary settling basin (Schroeder 1983) and associated chemical addition equipment.

The major cost items for confined aquatic, nearshore, and upland disposal are associated with site acquisition, dike and berm construction, and installation of liner and cap materials. Costs for these confined structure components depends on assumed fill depths. For the purposes of this evaluation, upland, nearshore, and confined aquatic disposal fill depths were assumed to be 15, 30, and 15 ft, respectively. The value of land for upland and nearshore disposal sites were estimated to be $25,000/ac and $43,000/ac, respectively (Rockey, M., 11 August 1987, personal communication). The costs for dike and weir construction were estimated by averaging costs for all potential sites presented in Table 5-4 of Phillips et al. (1985). Three foot liner depths were assumed for upland sites. In the absence of treatment, nearshore sites were assumed to contain a soil/bentonite cap ($4.20/yd^3$) without liner. Upland sites were assumed to contain a clay over dual synthetic liners complete with underdrain systems for leachate collection ($15.64/yd^3$). For the solidification alternative, a 3-ft clay cap ($4.20/yd^3$) and a 3-ft clay liner ($4.20/yd^3$) with underdrains ($0.12/yd^3$) was proposed for draining purposes. For solvent extraction and thermal treatment alternatives, a 1-ft clay liner ($1.40/yd^3$) was assumed and a 3-ft clay cap was assumed for the disposal facility. Cap depths of 3 ft were assumed for upland and nearshore, and a 6-ft cap was assumed for in situ capping. Material and installation costs for synthetic liners and caps were estimated from data provided by Phillips et al. (1985).

Intertidal habitat mitigation was assumed to be performed by clamshell dredging. Clean sediment was assumed to replace lost intertidal habitat on a volume per volume basis.

Operation and maintenance costs for upland and nearshore confinement options were assumed to consist of inspections, erosion control, repairs and maintenance of site vegetation. Costs for these items in addition to revegetation of the confinement area following completion of disposal operations were estimated from data provide by U.S. EPA (1985) Present worth of operation and maintenance costs were estimated with a 10 percent discount for 30 yr for all alternatives.

Monitoring programs will last from 5 to 30 yr depending on remedial alternatives. For open-water sites (i.e., in situ capping and confined aquatic disposal), it was assumed that one sample station per acre would be established with a maximum of 30 stations. For each sampling station, one core with three samples would be obtained for depth resolution. For treatment alternatives, annual sampling was assumed for the first 5 yr. In the absence of treatment, semiannual sampling was assumed to occur for the first 5 yr, followed by biannual sampling for years 6 to 30. Upland, nearshore, and land treatment options will use monitoring wells. For non-treated sediment disposal, one well per 25,000 yd^3 of sediment was assumed, with a maximum of 15 and a minimum of six wells per site. For disposal of treated sediments, a total of six monitoring wells will be installed up and downgradient of the site for leachate collection. A base cost of $1,200 per sample was assumed for chemical analysis.

TABLE D-1 Institutional Control Alternative

			Denny Way
		Depth (yd)	1
		Area (yd2)	220000
		Volume (yd3)	220000
	Unit		
INITIAL COSTS	Costs ($)		Cost ($)
Signs for Access Restrictions	$25,000 /site		$25,000
Contingency (20%)			$5,000
	Total Initial Costs		$30,000
O&M COSTS - Present Worth			
Monitoring Stations	1 station/10 acre		5
Core Acquisition	1 core/station	$1,500 /core	$70,725
Chemical analysis	3 sample/Station	$1,200 /sample at Denny Way	$169,740
		$1,200 /sample at N. Harbor Island	
(Annual sampling for 30 yr)			
Educational Programs	$15,000 /year		$141,450
	Contingency (20%)		$76,383
	Present Worth of O&M (10% Discount, 30 Yr)		$458,000
COST SUMMARY			
	Total Alternative Costs		$488,000

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TABLE D-1 Institutional Control Alternative

			N. Harbor Island
		Depth (yd)	1
		Area (yd2)	370000
		Volume (yd3)	370000
		Unit Costs ($)	Cost ($)
INITIAL COSTS			
Signs for Access Restrictions		$25,000 /site	$25,000
Contingency (20%)			$5,000
	Total Initial Costs		$30,000
O&M COSTS - Present Worth			
Monitoring Stations	1 station/10 acre		8
Core Acquisition	1 core/station	$1,500 /core	$113,160
Chemical analysis	3 sample/Station	$1,200 /sample at Denny Way	$271,584
		$1,200 /sample at N. Harbor Island	
(Annual sampling for 30 yr)			
Educational Programs		$15,000 /year	$141,450
	Contingency (20%)		$82,607
	Present Worth of O&M (10% Discount, 30 Yr)		$609,000
COST SUMMARY			
	Total Alternative Costs		$639,000

TABLE D-2 In-situ capping alternative

				Denny Way
			Depth (yd)	1.0
			Area (yd2)	220000
			Volume (yd3)	220000
		Unit Costs ($)		
INITIAL COSTS				
Sampling Program				
Sediment Core (one per 4,000 yd3)		$1,500 /core		$82,500
Chemical Analysis (one per 4,000 yd3)		waterway dependent		$66,000
In-situ Capping				
Dredge Operating Cost (6 ft cap)		$3.00 /yd2		$660,000
Barge Transport (up to 5 miles)		$1.00 /yd2		$220,000
Subtotal				$1,028,500
Contingency (20%)				$205,700
Mobilization, Bonding, Insurance (10%)				$102,850
Subtotal				$1,337,050
Administration, Engineering (15%)				$200,558
	Total Initial Costs			$1,538,000
O&M COSTS - Present Worth				
Site maintenance (30 yr)		$0.10 /yd2/yr		$207,460
Number of monitoring stations		1 station/acre (30 maximum)		30
Core Acquisition	1 core/station	$1,500 /core		$472,950
Chemical analysis	3 samples/statio	$1,200 /sample at Denny Way $1,200 /sample at N. Harbor Island		$1,135,080
Semi-annually for year 1 to 5 Every two years for year 6 to 30				
	Contingency (20%)			$363,098
	Present Worth of O&M Cost (10% Discount, 30 Years)			$2,179,000
COST SUMMARY				
	Total Alternative Costs			$3,717,000

TABLE D-3 Clamshell Dredge/Confined Aquatic Disposal Alternative

		Denny Way
	Depth (yd)	1
	Area (yd2)	220000
	Volume (yd3)	220000

INITIAL COSTS	Unit Costs ($)	Cost ($)
Sampling Program		
Sediment Core (one per 4,000 yd3)	$1,500 /core	$82,500
Chemical Analysis (one per 4,000 yd3)	waterway dependent	$66,000
Clamshell Dredge/Open-water CAD		
Clamshell Dredge of COM	$1.25 /yd3	$275,000
Clamshell Dredge Capping Materials	$0.25 /yd3	$55,000
Transport of COM (up to 5 mi)	$0.50 /yd3	$110,000
Transport of Capping Materials	$0.10 /yd3	$22,000
Subtotal		$610,500
Contingency (20%)		$122,100
Mobilization, Bonding, Insurance (10%)		$61,050
Subtotal		$793,650
Administration, Engineering (15%)		$119,048
	Total Initial Costs	$913,000

O&M COSTS - Present Worth			
Site maintenance (30 yrs)		$0.08 /yd3/yr	$165,968
Number of monitoring stations		1 station/acre (30 Maximum)	30
Core Acquisition	1 core/station	$1,500 /core	$472,950
Chemical analysis	3 samples/statio	$1,200 /sample at Denny Way	$1,135,080
		$1,200 /sample at N. Harbor Island	
Semi-annual sampling for yr 1-5			
Bi-annual sampling for yr 6-30			
	Contingency (20%)		$354,800
	Present Worth of O&M Costs (10% Discount, 30 yr)		$2,129,000
COST SUMMARY			
	Total Alternative Costs		$3,042,000

TABLE D-3 Clamshell Dredge/Confined Aquatic Disposal Alternative

			N. Harbor Island
		Depth (yd)	1
		Area (yd2)	370000
		Volume (yd3)	370000
INITIAL COSTS		Unit Costs ($)	Cost ($)
Sampling Program			
Sediment Core (one per 4,000 yd3)		$1,500 /core	$139,500
Chemical Analysis (one per 4,000 yd3)		waterway dependent	$111,600
Clamshell Dredge/Open-water CAD			
Clamshell Dredge of CDM		$1.25 /yd3	$462,500
Clamshell Dredge Capping Materials		$0.25 /yd3	$92,500
Transport of CDM (up to 5 mi)		$0.50 /yd3	$185,000
Transport of Capping Materials		$0.10 /yd3	$37,000
Subtotal			$1,028,100
Contingency (20%)			$205,620
Mobilization, Bonding, Insurance (10%)			$102,810
Subtotal			$1,336,530
Administration, Engineering (15%)			$200,480
	Total Initial Costs		$1,537,000
O&M COSTS - Present Worth			
Site maintenance (30 yrs)		$0.08 /yd3/yr	$279,128
Number of monitoring stations		1 station/acre (30 Maximum)	30
Core Acquisition	1 core/station	$1,500 /core	$472,950
Chemical analysis	3 samples/statio	$1,200 /sample at Denny Way $1,200 /sample at N. Harbor Island	$1,135,080
Semi-annual sampling for yr 1-5			
Bi-annual sampling for yr 6-30			
	Contingency (20%)		$377,432
	Present Worth of O&M Costs (10% Discount, 30 yr)		$2,265,000
COST SUMMARY			
	Total Alternative Costs		$3,802,000

TABLE D-4 Clamshell Dredge/Nearshore Disposal Alternative

			Denny Way
		Depth (yd)	1
		Area(yd2)	220000
		Volume (yd3)	220000
	Unit	Intertidal area (yd2)	37000
INITIAL COSTS	Costs ($)		Cost ($)
Site Acquisition (30 ft fill)	$43,000 /acre		$195,455
Site Preparation (10% Site Acquisition)			$19,545
Sampling Program			
Sediment Core (one per 4,000 yd3)	$1,500 /core		$82,500
Chemical Analysis (one per core)	waterway dependent		$66,000
Clamshell Dredge/Nearshore Disposal			
Dike and Weir Construction	$0.70 /yd3		$154,000
Clarification Unit Construction	$0.18 /yd3		$38,500
Clamshell Dredge	$1.25 /yd3		$275,000
Barge Transport (up to 5 miles)	$0.50 /yd3		$110,000
Clamshell CDM Placement	$1.25 /yd3		$275,000
Chemical Clarification	$0.20 /yd3		$44,000
Cap Placement	$2.10 /yd3		$462,000
Closure/Vegetation	$0.10 /yd3		$22,000
Intertidal mitigation	$1.75 /yd2		$64,750
Monitoring Wells	$2,000 /well		$18,000
Subtotal			$1,826,750
Contingency (20%)			$365,350
Mobilization, Bonding, Insurance (10%)			$182,675
Subtotal			$2,374,775
Administration, Engineering (15%)			$356,216
Total Initial Costs			$2,731,000

O&M COSTS - Present Worth

Site maintenance (30 yrs)		$0.08 /yd3/yr	$165,968
Number of monitoring wells		1 well/25000 yd3 (15 Max, 6 Min)	9
Chem analysis	1 samp/well	$1,200 /sample at Denny Way	$113,508
		$1,200 /sample at N. Harbor Island	
Semi-annual sampling for yr 1-5			
Annual sampling for yr 6-30			
Contingency (20%)			$55,895
Present Worth O&M Costs (10% Discount, 30 Yr)			$335,000

COST SUMMARY

Total Alternative Costs	$3,066,000

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TABLE D-4 Clamshell Dredge/Nearshore Disposal Alternative

			N. Harbor Island
		Depth (yd)	1
		Area(yd2)	370000
		Volume (yd3)	370000
		Intertidal area (yd2)	62000
INITIAL COSTS	Unit Costs ($)		Cost ($)
Site Acquisition (30 ft fill)	$43,000 /acre		$328,719
Site Preparation (10% Site Acquisition)			$32,872
Sampling Program			
Sediment Core (one per 4,000 yd3)	$1,500 /core		$139,500
Chemical Analysis (one per core)	waterway dependent		$111,600
Clamshell Dredge/Nearshore Disposal			
Dike and berm construction	$0.70 /yd3		$259,000
Clamshell Dredge	$1.25 /yd3		$462,500
Barge Transport (up to 5 miles)	$0.50 /yd3		$185,000
Clamshell CDM Placement	$1.25 /yd3		$462,500
Cap Placement	$2.10 /yd3		$777,000
Closure/Vegetation	$0.10 /yd3		$37,000
Intertidal mitigation	$1.75 /yd2		$108,500
Monitoring Wells	$2,000 /well		$30,000
Subtotal			$2,934,191
Contingency (20%)			$586,838
Mobilization, Bonding, Insurance (10%)			$293,419
Subtotal			$3,814,448
Administration, Engineering (15%)			$572,167
Total Initial Costs			$4,387,000
O&M COSTS - Present Worth			
Site maintenance (30 yrs)	$0.08 /yd3/yr		$279,128
Number of monitoring wells	1 well/25000 yd3 (15 Max, 6 Min)		15
Chem analysis 1 samp/well	$1,200 /sample at Denny Way		$189,180
	$1,200 /sample at N. Harbor Island		
Semi-annual sampling for yr 1-5			
Annual sampling for yr 6-30			
Contingency (20%)			$93,662
Present Worth O&M Costs (10% Discount, 30 Yr)			$562,000
COST SUMMARY			
Total Alternative Costs			$4,949,000

TABLE D-5 Clamshell Dredge/Upland Disposal Alternative

		Denny Way
	Depth (yd)	1
	Area (yd2)	220000
	Volume (yd3)	220000

INITIAL COSTS	Unit Costs ($)	Cost ($)
Site Acquisition (15 ft fill)	$25,000 /acre	$227,273
Site Preparation (10% Site Acquisition)		$22,727
Sampling Program		
Sediment Core (one per 4,000 yd3)	$1,500 /core	$82,500
Chemical Analysis (one per core)	Waterway Dependent	$66,000
Clamshell Dredge/Upland Disposal		
Clamshell dredging	$1.25 /yd3	$275,000
Sediment rehandling	$1.00 /yd3	$220,000
Barge transport (up to 5 mi)	$0.50 /yd3	$110,000
Truck transport (2 mi)	$2.01 /yd3	$442,200
Dike and Berm	$0.35 /yd3	$77,000
Clarification Unit Construction	$0.09 /yd3	$19,800
Liner-Drainage Sand/Gravel (1 ft layer)	$0.80 /yd3	$176,000
Liner-Primary Underdrain System	$0.12 /yd3	$26,400
Liner-Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3	$220,000
Liner-Leachate Collection System	$0.12 /yd3	$26,400
Liner-Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3	$220,000
Liner-Clay Bottom Liner	$4.20 /yd3	$924,000
Cap-Topsoil Vegetative Layer (2 ft)	$2.40 /yd3	$528,000
Cap-Drainage Sand/Gravel (1 ft layer)	$0.80 /yd3	$176,000
Cap-Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3	$220,000
Cap-Clay Primary Liner (3 ft)	$4.20 /yd3	$1,155,000
Dredge Water Clarification	$0.20 /yd3	$15,400
Revegetation	$0.20 /yd3	$44,000
Intertidal mitigation	$1.75 /yd3	$0
Monitoring Wells	$2,000 /well	$18,000
Subtotal		$5,291,700
Contingency (20%)		$1,058,340
Mobilization, Bonding, Insurance (10%)		$529,170
Subtotal		$6,879,210
Administration, Engineering (15%)		$1,031,882
Total Initial Costs		$7,911,000

O&M COSTS - Present Worth		
Site maintenance (30 yr)	$0.16 /yd3/yr	$331,936
Number of monitoring wells	1 well/25000 yd3 (15 max, 6 min)	9
Chem analysis 1 samp/well	$1,200 /sample at Denny Way	$113,508
	$1,200 /sample at N. Harbor Island	
Semi-annual sampling for yr 1-5		
Bi-annual sampling yr 6-30		
Contingency (20%)		$89,089
Present Worth of O&M Costs (10% Discount, 30 yr)		$535,000

COST SUMMARY	
Total Alternative Costs	$8,446,000

TABLE D-5 Clamshell Dredge/Upland Disposal Alternative

	N. Harbor Island
Depth (yd)	1
Area (yd2)	370000
Volume (yd3)	370000

INITIAL COSTS	Unit Costs ($)	Cost ($)
Site Acquisition (15 ft fill)	$25,000 /acre	$382,231
Site Preparation (10% Site Acqusition)		$38,223
Sampling Program		
Sediment Core (one per 4,000 yd3)	$1,500 /core	$139,500
Chemical Analysis (one per core)	Waterway Dependent	$111,600
Clamshell Dredge/Upland Disposal		
Clamshell dredging	$1.25 /yd3	$462,500
Barge transport (up to 5 mi)	$0.50 /yd3	$185,000
Sediment rehandling	$1.00 /yd3	$370,000
Truck transport (2 mi)	$2.01 /yd3	$743,700
Dike and Berm	$0.35 /yd3	$129,500
Clarification Unit Construction	$0.09 /yd3	$33,300
Liner-Drainage Sand/Gravel (1 ft layer)	$0.80 /yd3	$296,000
Liner-Primary Underdrain System	$0.12 /yd3	$44,400
Liner-Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3	$370,000
Liner-Leachate Collection System	$0.12 /yd3	$44,400
Liner-Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3	$370,000
Liner-Clay Bottom Liner	$4.20 /yd3	$1,554,000
Cap-Topsoil Vegetative Layer (2 ft)	$2.40 /yd3	$888,000
Cap-Drainage Sand/Gravel (1 ft layer)	$0.80 /yd3	$296,000
Cap-Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3	$370,000
Cap-Clay Primary Liner (3 ft)	$4.20 /yd3	$1,942,500
Dredge Water Clarification	$0.20 /yd3	$25,900
Revegetation	$0.20 /yd3	$74,000
Intertidal mitigation	$1.75 /yd3	$0
Monitoring Wells	$2,000 /well	$30,000
Subtotal		$8,900,755
Contingency (20%)		$1,780,151
Mobilization, Bonding, Insurance (10%)		$890,075
Subtotal		$11,570,981
Administration, Engineering (15%)		$1,735,647
Total Initial Costs		$13,307,000
O&M COSTS - Present Worth		
Site maintenance (30 yr)	$0.16 /yd3/yr	$558,256
Number of monitoring wells	1 well/25000 yd3 (15 max, 6 min)	15
Chem analysis 1 samp/well	$1,200 /sample at Denny Way	$189,180
	$1,200 /sample at N. Harbor Island	
Semi-annual sampling for yr 1-5		
Bi-annual sampling yr 6-30		
Contingency (20%)		$149,487
Present Worth of O&M Costs (10% Discount, 30 yr)		$897,000
COST SUMMARY		
Total Alternative Costs		$14,204,000

TABLE D-6. Clamshell Dredge/Solidification/Upland Disposal Alternative

	Denny Way
Depth (yd)	1
Area (yd2)	220000
Volume (yd3)	220000

INITIAL COSTS		Unit Costs ($)	Cost ($)
Site Acquisition (15 ft fill)		$25,000 /acre	$227,273
Site Preparation (10% Site Acqusition)			$22,727
Sampling Program			
Sediment Core (one per 4,000 yd3)		$1,500 /core	$82,500
Chemical Analysis (one per core)		waterway dependent	$66,000
Clamshell Dredge/Solidfication/Upland Disposal			
Dike and Berm Construction		$0.40 /yd3	$88,000
Clarification Unit Construction		$0.10 /yd3	$22,000
Clamshell dredging		$1.25 /yd3	$275,000
Barge transport (up to 5 mi)		$0.50 /yd3	$110,000
Truck transport (2 mi)		$2.01 /yd3	$442,200
Sediment rehandling		$1.00 /yd3	$220,000
Liner (3 ft clay)		$4.20 /yd3	$924,000
Underdrain		$0.12 /yd3	$26,400
Chemical Clarification		$0.20 /yd3	$44,000
Solidification		$25.00 /yd3	$5,500,000
Cover (3 ft clay or soil)		$4.20 /yd3	$924,000
Revegetation		$0.12 /yd3	$26,400
Monitoring Wells		$2,000 /well	$12,000
Subtotal			$9,012,500
Contingency (20%)			$1,802,500
Mobilization, Bonding, Insurance (10%)			$901,250
Subtotal			$11,716,250
Administration, Engineering (15%)			$1,757,438
Total Initial Costs			$13,474,000
O&M UNIT COSTS			
Site maintenance (30 yr)		$0.16 /yd3	$331,936
Monitoring we	6 wells/site		6
Chemical anal	1 sample/well	$1,200 /sample at Denny Way $1,200 /sample at N. Harbor Island	$27,288
Annual sampling for 5 yr			
Contingency (20%)			$71,845
Present Worth of O&M Costs (10% Discount, 30 yr maintenance, 5 yr monitoring)			$431,000
COST SUMMARY			
Total Alternative Costs			$13,905,000

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TABLE D-6 Clamshell Dredge/Solidification/Upland Disposal Alternative

			N. Harbor Island
		Depth (yd)	1
		Area (yd2)	370000
		Volume (yd3)	370000

INITIAL COSTS		Unit Costs ($)	Cost ($)
Site Acquisition (15 ft fill)		$25,000 /acre	$382,231
Site Preparation (10% Site Acquisition)			$38,223
Sampling Program			
Sediment Core (one per 4,000 yd3)		$1,500 /core	$139,500
Chemical Analysis (one per core)		waterway dependent	$111,600
Clamshell Dredge/Solidfication/Upland Disposal			
Dike and Berm Construction		$0.40 /yd3	$148,000
Clarification Unit Construction		$0.10 /yd3	$37,000
Clamshell dredging		$1.25 /yd3	$462,500
Barge transport (up to 5 mi)		$0.50 /yd3	$185,000
Truck transport (2 mi)		$2.01 /yd3	$743,700
Pipeline Boosters (2 units)		$1.00 /yd3	$370,000
Liner (3 ft clay)		$4.20 /yd3	$1,554,000
Underdrain		$0.12 /yd3	$44,400
Chemical Clarification		$0.20 /yd3	$74,000
Solidification		$25.00 /yd3	$9,250,000
Cover (3 ft clay or soil)		$4.20 /yd3	$1,554,000
Revegetation		$0.12 /yd3	$44,400
Monitoring Wells		$2,000 /well	$12,000
Subtotal			$15,150,555
Contingency (20%)			$3,030,111
Mobilization, Bonding, Insurance (10%)			$1,515,055
Subtotal			$19,695,721
Administration, Engineering (15%)			$2,954,358
Total Initial Costs			$22,650,000
O&M UNIT COSTS			
Site maintenance (30 yr)		$0.16 /yd3	$558,256
Mon. wells	6 wells/site		6
Chem analysis	1 sample/well	$1,200 /sample at Denny Way $1,200 /sample at N. Harbor Island	$27,288
Annual sampling for 5 yr			
Contingency (20%)			$117,109
Present Worth of O&M Costs (10% Discount, 30 yr maintenance, 5 yr monitoring)			$703,000
COST SUMMARY			
Total Alternative Costs			$23,353,000

TABLE D-7 Clamshell Dredge/Solvent Extraction/Upland Disposal Alternative

			N. Harbor Island
		Depth (yd)	1
		Area (yd2)	370000
		Volume (yd3)	370000

INITIAL COSTS		Unit Costs ($)		Cost ($)
Site Acquisition (15 ft fill)		$25,000 /acre		$382,231
Site Preparation (10% Site Acquisition)				$38,223
Sampling Program				
Sediment Core (one per 4,000 yd3)		$1,500 /core		$139,500
Chemical Analysis (one per 4,000 yd3)		waterway dependent		$111,600
Clamshell Dredge/Solvent Extraction/Upland Disposal				
Dike and Berm Construction		$0.40 /yd3		$148,000
Clamshell Dredge		$1.25 /yd3		$462,500
Barge Transport (up to 5 miles)		$0.50 /yd3		$185,000
Truck Transport (2 miles)		$2.01 /yd3		$743,700
Clamshell Unload		$1.25 /yd3		$462,500
Solvent Extraction		$120 /yd3		$44,400,000
Cap (3 ft clay)		$4.20 /yd3		$1,554,000
Liner (1 ft clay)		$1.40 /yd3		$518,000
Revegetation		$0.12 /yd3		$44,400
Monitoring Wells		$2,000 /well		$12,000
Subtotal				$49,201,655
Contingency (20%)				$9,840,331
Mobilization, Bonding, Insurance (10%)				$4,920,165
Subtotal				$63,962,151
Administration, Engineering (15%)				$9,594,323
	Total Initial Costs			$73,556,000
O&M COSTS - Present Worth				
Site maintenance (30 yr)		$0.16 /yd3/yr		$558,256
Monitoring wells	6 wells/site			6
Chemical analysis	1 sample/well	$1,200 /sample at Denny Way		$27,288
		$1,200 /sample at N. Harbor Island		
Annual sampling for 5 yr				
	Contingency (20%)			$117,109
	Present Worth of O&M Costs (10% Discount, 5 yr monitoring, 30 yr maintenance)			$703,000
COST SUMMARY				
	Total Alternative Costs			$74,259,000

TABLE D-8 Hydraulic Dredge and Confined Aquatic Disposal

			Target	Mouth City 10 Yrs	Max. AET
		Depth (yd)	1.00	1.00	0.00
		Area (yd2)	152000	59000	0
		Volume (yd3)	152000	59000	0
INITIAL COSTS	Unit Costs ($)		Target Cost ($)	10 Yrs Costs ($)	Max. AET Costs ($)
Hydraulic Dredge/CAD (Waterway)					
Clamshell Dredge of Contaminated Sedime (1 acre, with site specific depth)	$1.25 /yd3		$6,050	$6,050	$0
Transport (2 to 5 mi) and Disposal	$0.50 /yd3		$2,420	$2,420	$0
Clamshell Dredge Clean Sediment (3.75 ft cap over 10ft bed of CDM)	$1.25 /yd3		$2,269	$2,269	$0
Hydraulic Dredge of Contaminated Sedime followed by underlaying clean sediments to provide 6 ft cap	$1.50 /yd3		$662,220	$243,720	$0
Subtotal			$672,959	$254,459	$0
Contingency (20%)			$134,592	$50,892	$0
Mobilization, Bonding, Insurance (10%)			$67,296	$25,446	$0
Subtotal			$874,846	$330,796	$0
Administration, Engineering (15%)			$131,227	$49,619	$0
Total Initial Costs			$1,006,000	$380,000	$0
O&M COSTS - Present Worth					
Site maintenance (30 yr)	$0.08 /yd3/yr		$186,899	$72,546	$0
Number of monitoring stations	1 station/acre (30 Maximum)		30	14	0
Core Acquisition — 1 core/statio	$1,500 /core		$637,650	$297,570	$0
Chemical analysis — 3 samples/sta	$1,500 /sample at Head Hylebos $1,000 /sample at Mouth Hylebos $1,500 /sample at Sitcum $800 /sample at St. Paul $900 /sample at Middle $800 /sample at Mouth City $1,500 /sample at Head City $1,200 /sample at Wheeler Osgood $2,300 /sample at Ruston-Pt. Defiance		$1,020,240	$476,112	$0
Semi-annually for year 1 to 5 Every two years for year 6 to 30					
	Contingency (20%)		$368,958	$169,246	$0
	Present Worth of O&M Costs (5% Discount, 30 yr)		$2,214,000	$1,015,000	$0
COST SUMMARY	Total Alternative Costs		$3,220,000	$1,395,000	$0

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TABLE D-9 Hydraulic Dredge/Nearshore Disposal Alternative

		Target	Sitcum 10 yr	Max. AET
Depth (yd)		1	1	1
Area (yd2)		152000	83000	134000
Volume (yd3)		152000	83000	134000
Intertidal (yd3)		0	0	0
INITIAL COSTS	Unit Costs ($)	Cost ($)	Costs ($)	Costs ($)
Site Acquisition (30 ft fill)	$43,000 /acre	$135,041	$73,740	$119,050
Site Preparation (10% Site Acquisition)		$13,504	$7,374	$11,905
Sampling Program				
Sediment Core (one per 4,000 yd3)	$1,500 /core	$57,000	$57,000	$57,000
Chemical Analysis (one per core)	waterway dependent	$57,000	$57,000	$57,000
Hydraulic Dredge/Nearshore Disposal				
Dike and Weir Construction	$0.70 /yd3	$106,400	$58,100	$93,800
Clarification Unit Construction	$0.18 /yd3	$26,600	$14,525	$23,450
Cutterhead Operating Cost	$1.50 /yd3	$228,000	$124,500	$201,000
Pipeline Booster	$0.50 /yd3	$76,000	$41,500	$67,000
Chemical Clarification	$0.35 /yd3	$53,200	$29,050	$46,900
Cap Placement	$2.10 /yd3	$319,200	$174,300	$281,400
Closure/Vegetation	$0.10 /yd3	$15,200	$8,300	$13,400
Intertidal Mitigation	$1.75 /yd3	$0	$0	$0
Monitoring Wells	$2,000 /well	$12,000	$12,000	$12,000
Subtotal		$1,251,145	$740,389	$1,117,905
Contingency (20%)		$250,229	$148,078	$223,581
Mobilization, Bonding, Insurance (10%)		$125,115	$74,039	$111,790
Subtotal		$1,626,489	$962,505	$1,453,276
Administration, Engineering (15%)		$243,973	$144,376	$217,991
Total Initial Costs		$1,870,000	$1,107,000	$1,671,000
O&M COSTS - Present Worth				
Site maintenance (30 yr)	$0.08 /yd3/yr	$114,669	$62,615	$101,090
Number of monitoring wells	1 well/25000 yd3 (15 Max, 6 Min)	6	6	6
Chemical anal 1 sample/well	$1,500 /sample at Head Hylebos	$94,590	$94,590	$94,590
	$1,000 /sample at Mouth Hylebos			
Semi-annually for yr 1 to 5	$1,500 /sample at Sitcum			
Annually for yr 6 to 30	$800 /sample at St. Paul			
	$900 /sample at Middle			
	$800 /sample at Mouth City			
	$1,500 /sample at Head City			
	$1,200 /sample at Wheeler Osgood			
	$2,300 /sample at Ruston-Pt. Defiance			
Contingency (20%)		$41,852	$31,441	$39,136
Present Worth O&M Costs (10% Discount, 30 yr)		$251,000	$189,000	$235,000
COST SUMMARY				
Total Alternative Costs		$2,121,000	$1,296,000	$1,906,000

TABLE D-10 Hydraulic Dredge/Upland Disposal Alternative

		Example		
	Depth (yd)	1	0.5	1
	Area (yd2)	220000	220000	370000
	Volume (yd3)	220000	110000	370000
INITIAL COSTS	Unit Costs ($)	Cost ($)	Costs ($)	Costs ($)
Site Acquisition (15 ft [illegible])	$25,000 /acre	$227,273	$113,636	$382,231
Site Preparation (10% Site Acquisition)		$22,727	$11,364	$38,223
Sampling Program				
Sediment Core (one per 4,000 yd3)	$1,500 /core	$82,500	$82,500	$139,500
Chemical Analysis (one per core)	Waterway Dependent	$66,000	$66,000	$111,600
Hydraulic Dredge/Upland Disposal				
Cutterhead	$1.50 /yd3	$330,000	$165,000	$555,000
Pipeline Boosters (2 units)	$1.00 /yd3	$220,000	$110,000	$370,000
Dike and Berm	$0.35 /yd3	$77,000	$38,500	$129,500
Clarification Unit Construction	$0.09 /yd3	$19,800	$9,900	$33,300
Liner-Drainage Sand/Gravel (1 ft layer)	$0.80 /yd3	$176,000	$88,000	$296,000
Liner-Primary Underdrain System	$0.12 /yd3	$26,400	$13,200	$44,400
Liner-Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3	$220,000	$110,000	$370,000
Liner-Leachate Collection System	$0.12 /yd3	$26,400	$13,200	$44,400
Liner-Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3	$220,000	$110,000	$370,000
Liner-Clay Bottom Liner	$4.20 /yd3	$924,000	$462,000	$1,554,000
Cap-Topsoil Vegetative Layer (2 ft)	$2.40 /yd3	$528,000	$264,000	$888,000
Cap-Drainage Sand/Gravel (1 ft layer)	$0.80 /yd3	$176,000	$88,000	$296,000
Cap-Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3	$220,000	$110,000	$370,000
Cap-Clay Primary Liner (3 ft)	$4.20 /yd3	$1,386,000	$693,000	$2,331,000
Dredge Water Clarification	$0.35 /yd3	$26,950	$13,475	$45,325
Revegetation	$0.20 /yd3	$44,000	$22,000	$74,000
Monitoring Wells	$2,000 /well	$18,000	$12,000	$30,000
Subtotal		$5,037,050	$2,595,775	$8,472,480
Contingency (20%)		$1,007,410	$519,155	$1,694,496
Mobilization, Bonding, Insurance (10%)		$503,705	$259,578	$847,248
Subtotal		$6,548,165	$3,374,508	$11,014,223
Administration, Engineering (15%)		$982,225	$506,176	$1,652,134
Total Initial Costs		$7,530,000	$3,881,000	$12,666,000
O&M COSTS - Present Worth				
Site maintenance (30 yr)	$0.16 /yd3/yr	$331,936	$165,968	$558,256
Number of monitoring wells	1 well/25000 yd3 (15 max, 6 min)	9	6	15
Chem analysis 1 samp/well	$1,200 /sample	$113,508	$75,672	$189,180
	$1,200 /sample			
Semi-annual sampling for yr 1-5	$1,200 /sample			
Bi-annual sampling yr 6-30				
Contingency (20%)		$89,089	$48,328	$149,487
Present Worth of O&M Costs (10% Discount, 30 yr)		$635,000	$290,000	$897,000
COST SUMMARY				
Total Alternative Cos		$8,065,000	$4,171,000	$13,563,000

TABLE D-11 Clamshell Dredge/Thermal Treatment/Upland Disposal Alternative

			Head Hylebos		
			Target	10 yr	Max. AET
		Depth (yd)	0.5	0.5	0.75
		Area (yd2)	437000	328000	36000
		Volume (yd3)	328000	246000	27000
		Intertidal (yd3)	12000	7000	0
	Unit		Target	10 yr	Max. AET
INITIAL COSTS	Costs ($)		Cost ($)	Costs ($)	Costs ($)
Site Acquisition (15 ft fill)	$25,000 /acre		$338,843	$254,132	$27,893
Site Preparation (10% Site Acquisition)			$33,884	$25,413	$2,789
Sampling Program					
Sediment Core (one per 4,000 yd3)	$1,500 /core		$123,000	$123,000	$123,000
Chemical Analysis (one per core)	waterway dependent		$123,000	$123,000	$123,000
Clamshell Dredge/Solvent Extraction/Upland Disposal					
Dike and Berm Construction	$0.40 /yd3		$131,200	$98,400	$10,800
Clamshell Dredge	$1.25 /yd3		$410,000	$307,500	$33,750
Barge Transport (2 miles)	$0.50 /yd3		$164,000	$123,000	$13,500
Truck Transport (2 miles)	$2.01 /yd3		$659,280	$494,460	$54,270
Clamshell Unload	$1.25 /yd3		$410,000	$307,500	$33,750
Thermal Treatment	$300 /yd3		$98,400,000	$73,800,000	$8,100,000
Liner (1 ft clay)	$1.40 /yd3		$459,200	$344,400	$37,800
Cap (3 ft clay)	$4.20 /yd3		$1,377,600	$1,033,200	$113,400
Revegetation	$0.12 /yd3		$39,360	$29,520	$3,240
Intertidal Mitigation	$1.75 /yd3		$21,000	$12,250	$0
Monitoring Wells	$2,000 /well		$12,000	$12,000	$12,000
Subtotal			$102,702,367	$77,087,775	$8,689,192
Contingency (20%)			$20,540,473	$15,417,555	$1,737,838
Mobilization, Bonding, Insurance (10%)			$10,270,237	$7,708,778	$868,919
Subtotal			$133,513,077	$100,214,108	$11,295,949
Administration, Engineering (15%)			$20,026,962	$15,032,116	$1,694,392
Total Initial Costs			$153,540,000	$115,246,000	$12,990,000
O&M COSTS - Present Worth					
Site maintenance (30 yr)	$0.16 /yd3/yr		$494,886	$39,360	$4,320
Monitor. well	6 well/site		6	6	6
Chemical anal	1 samp/well	$1,500 /sample at Head Hylebos	$34,110	$34,110	$34,110
		$1,000 /sample at Mouth Hylebos			
Annual sampling for 5 yr		$1,500 /sample at Sitcum			
		$800 /sample at St. Paul			
		$900 /sample at Middle			
		$800 /sample at Mouth City			
		$1,500 /sample at Head City			
		$1,200 /sample at Wheeler Osgood			
		$2,300 /sample at Ruston-Pt. Defiance			
Contingency (20%)			$105,799	$14,694	$7,686
Present Worth of O&M Costs (10% Discount, 5 yr monitoring, 30 yr maintenance)			$635,000	$88,000	$46,000
COST SUMMARY					
Total Alternative Costs			$154,175,000	$115,334,000	$13,036,000

TABLE D-11 Clamshell Dredge/Thermal Treatment/Upland Disposal Alternative

		Mouth Hylebos		
		Target	10 yr	Max. AET
	Depth (yd)	2	2	2
	Area (yd2)	217000	98000	182000
	Volume (yd3)	433000	196000	364000
	Intertidal (yd3)	83000	0	0
INITIAL COSTS	Unit Costs ($)	Target Cost ($)	10 yr Costs ($)	Max. AET Costs ($)
Site Acquisition (15 ft fill)	$25,000 /acre	$447,314	$202,479	$376,033
Site Preparation (10% Site Acquisition)		$44,731	$20,248	$37,603
Sampling Program				
Sediment Core (one per 4,000 yd3)	$1,500 /core	$162,000	$162,000	$162,000
Chemical Analysis (one per core)	waterway dependent	$108,000	$108,000	$108,000
Clamshell Dredge/Solvent Extraction/Upland Disposal				
Dike and Berm Construction	$0.40 /yd3	$173,200	$78,400	$145,600
Clamshell Dredge	$1.25 /yd3	$541,250	$245,000	$455,000
Barge Transport (2 miles)	$0.50 /yd3	$216,500	$98,000	$182,000
Truck Transport (2 miles)	$2.01 /yd3	$870,330	$393,960	$731,640
Clamshell Unload	$1.25 /yd3	$541,250	$245,000	$455,000
Thermal Treatment	$300 /yd3	$129,900,000	$58,800,000	$109,200,000
Liner (1 ft clay)	$1.40 /yd3	$606,200	$274,400	$509,600
Cap (3 ft clay)	$4.20 /yd3	$1,818,600	$823,200	$1,528,800
Revegetation	$0.12 /yd3	$51,960	$23,520	$43,680
Intertidal Mitigation	$1.75 /yd3	$145,250	$0	$0
Monitoring Wells	$2,000 /well	$12,000	$12,000	$12,000
Subtotal		$135,638,585	$61,486,207	$113,946,956
Contingency (20%)		$27,127,717	$12,297,241	$22,789,391
Mobilization, Bonding, Insurance (10%)		$13,563,859	$6,148,621	$11,394,696
Subtotal		$176,330,161	$79,932,069	$148,131,043
Administration, Engineering (15%)		$26,449,524	$11,989,810	$22,219,656
Total Initial Costs		$202,780,000	$91,922,000	$170,351,000
O&M COSTS - Present Worth				
Site maintenance (30 yr)	$0.16 /yd3/yr	$69,280	$31,360	$58,240
Monitor. well 6 well/site		6	6	6
Chemical anal 1 samp/well	$1,500 /sample at Head Hylebos	$22,740	$22,740	$22,740
	$1,000 /sample at Mouth Hylebos			
Annual sampling for 5 yr	$1,500 /sample at Sitcum			
	$800 /sample at St. Paul			
	$900 /sample at Middle			
	$800 /sample at Mouth City			
	$1,500 /sample at Head City			
	$1,200 /sample at Wheeler Osgood			
	$2,300 /sample at Ruston-Pt. Defiance			
Contingency (20%)		$18,404	$10,820	$16,196
Present Worth of O&M Costs (10% Discount, 5 yr monitoring, 30 yr maintenanc		$110,000	$65,000	$97,000
COST SUMMARY				
Total Alternative Costs		$202,890,000	$91,987,000	$170,448,000

TABLE D-12 Clamshell Dredge/Land Treatment Alternative

			Head Hylebos		
		Depth (yd)	0.5	0.5	0.75
		Area(yd2)	437000	328000	36000
		Volume (yd3)	328000	246000	27000
		Intertidal (yd3)	12000	7000	0
INITIAL COSTS	Unit Costs ($)		Target Cost ($)	10 yr Costs ($)	Max. AET Costs ($)
Site Acquisition (1 ft layer)	$25,000 /yd3		$5,082,645	$3,811,983	$418,388
Site Preparation (10% Site Acquisition)			$508,264	$381,198	$41,839
Sampling Program					
Sediment Core (one per 4,000 yd3)	$1,500 /core		$123,000	$123,000	$123,000
Chemical Analysis (one per 4,000 yd3)	waterway dependent		$123,000	$123,000	$123,000
Treatability Study	$100,000		$100,000	$100,000	$100,000
Sediment Removal					
Bucket Modification	$20,000		$20,000	$20,000	$20,000
Dredge Operation Cost	$1.25 /yd3		$410,000	$307,500	$33,750
Barge Transport (up to 5 miles)	$0.50 /yd3		$164,000	$123,000	$13,500
Clamshell Unload (200 yd3/hr)	$1.25 /yd3		$410,000	$307,500	$33,750
Truck Transport (2 miles)	$2.01 /yd3		$659,280	$494,460	$54,270
Intertidal Mitigation	$1.75 /yd3		$21,000	$12,250	$0
Treatment and Disposal					
Run-on and Run-off Control	$0.20 /yd3		$65,600	$49,200	$5,400
Monitoring Wells	$2,000 /well		$26,000	$12,000	$12,000
Lysimeters (20 per site)	$250 /each		$5,000	$5,000	$5,000
Subtotal			$7,717,789	$5,870,092	$983,897
Contingency (20%)			$1,543,558	$1,174,018	$196,779
Mobilization, Bonding, Insurance (10%)			$771,779	$587,009	$98,390
Subtotal			$10,033,126	$7,631,119	$1,279,066
Administration, Engineering (15%)			$1,504,969	$1,144,668	$191,860
Total Initial Costs			$11,538,000	$8,776,000	$1,471,000
O&M COSTS - Present Worth					
Site maintenance (30 yr)	$0.32 /yd3		$989,773	$78,720	$8,640
Number of monitoring wells	1 well/25000 yd3 (15 max, 6 min)		13	6	6
Chemical analysis 1 samples/well	$1,500 /sample at Head Hylebos		$204,945	$94,590	$94,590
	$1,000 /sample at Mouth Hylebos				
Semi-annually for year 1 to 5	$1,500 /sample at Sitcum				
Every two years for year 6 to 30	$800 /sample at St. Paul				
	$900 /sample at Middle				
	$800 /sample at Mouth City				
	$1,500 /sample at Head City				
	$1,200 /sample at Wheeler Osgood				
	$2,300 /sample at Ruston-Pt. Defiance				
Contingency (20%)			$238,944	$34,662	$20,646
Present Worth of O&M Costs (10% Discount, 30 yr)			$1,434,000	$208,000	$124,000
COST SUMMARY					
Total Alternative Costs			$12,972,000	$8,984,000	$1,595,000

TABLE D-12 Clamshell Dredge/Land Treatment Alternative

			Mouth Hylebos		
		Depth (yd)	2	2	2
		Area(yd2)	217000	98000	182000
		Volume (yd3)	433000	196000	364000
		Intertidal (yd3)	83000	0	0
INITIAL COSTS	Unit Costs ($)		Target Cost ($)	10 yr Costs ($)	Max. AET Costs ($)
Site Acquisition (1 ft layer)	$25,000 /yd3		$6,709,711	$3,037,190	$5,640,496
Site Preparation (10% Site Acquisition)			$670,971	$303,719	$564,050
Sampling Program					
Sediment Core (one per 4,000 yd3)	$1,500 /core		$162,000	$162,000	$162,000
Chemical Analysis (one per 4,000 yd3)	waterway dependent		$108,000	$108,000	$108,000
Treatability Study	$100,000		$100,000	$100,000	$100,000
Sediment Removal					
Bucket Modification	$20,000		$20,000	$20,000	$20,000
Dredge Operation Cost	$1.25 /yd3		$541,250	$245,000	$455,000
Barge Transport (up to 5 miles)	$0.50 /yd3		$216,500	$98,000	$182,000
Clamshell Unload (200 yd3/hr)	$1.25 /yd3		$541,250	$245,000	$455,000
Truck Transport (2 miles)	$2.01 /yd3		$870,330	$393,960	$731,640
Intertidal Mitigation	$1.75 /yd3		$145,250	$0	$0
Treatment and Disposal					
Run-on and Run-off Control	$0.20 /yd3		$86,600	$39,200	$72,800
Monitoring Wells	$2,000 /well		$30,000	$30,000	$30,000
Lysimeters (20 per site)	$250 /each		$5,000	$5,000	$5,000
Subtotal			$10,206,862	$4,787,069	$8,525,985
Contingency (20%)			$2,041,372	$957,414	$1,705,197
Mobilization, Bonding, Insurance (10%)			$1,020,686	$478,707	$852,599
Subtotal			$13,268,920	$6,223,190	$11,083,781
Administration, Engineering (15%)			$1,990,338	$933,478	$1,662,567
Total Initial Costs			$15,259,000	$7,157,000	$12,746,000
O&M COSTS - Present Worth					
Site maintenance (30 yr)	$0.32 /yd3		$138,560	$62,720	$116,480
Number of monitoring wells	1 well/25000 yd3 (15 max, 6 min)		15	15	15
Chemical analysis 1 samples/well	$1,500 /sample at Head Hylebos		$157,650	$157,650	$157,650
	$1,000 /sample at Mouth Hylebos				
Semi-annually for year 1 to 5	$1,500 /sample at Sitcum				
Every two years for year 6 to 30	$800 /sample at St. Paul				
	$900 /sample at Middle				
	$800 /sample at Mouth City				
	$1,500 /sample at Head City				
	$1,200 /sample at Wheeler Osgood				
	$2,300 /sample at Ruston-Pt. Defiance				
Contingency (20%)			$59,242	$44,074	$54,826
Present Worth of O&M Costs (10% Discount, 30 yr)			$355,000	$264,000	$329,000
COST SUMMARY					
Total Alternative Costs			$15,614,000	$7,421,000	$13,075,000

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TABLE D-13 Hydraulic Dredge/Solidification/Upland Disposal Alternative

			Example	
		Depth (yd)	1	0.5
		Area (yd2)	220000	220000
		Volume (yd3)	220000	110000
INITIAL COSTS		Unit Costs ($)	Cost ($)	Costs ($)
Site Acquisition (15 ft fill)		$25,000 /acre	$227,273	$113,636
Site Preparation (10% Site Acquisition)			$22,727	$11,364
Sampling Program				
Sediment Core (one per 4,000 yd3)		$1,500 /core	$82,500	$82,500
Chemical Analysis (one per core)		waterway dependent	$66,000	$66,000
Hydraulic Dredge/Solidfication/Upland Disposal				
Dike and Berm Construction		$0.40 /yd3	$88,000	$44,000
Clarification Unit Construction		$0.10 /yd3	$22,000	$11,000
Cutterhead (3 mile transport)		$1.50 /yd3	$330,000	$165,000
Pipeline Boosters (2 units)		$1.00 /yd3	$220,000	$110,000
Liner (3 ft clay)		$4.20 /yd3	$924,000	$462,000
Underdrain		$0.12 /yd3	$26,400	$13,200
Chemical Clarification		$0.35 /yd3	$77,000	$38,500
Solidification		$25.00 /yd3	$5,500,000	$2,750,000
Cover (3 ft clay or soil)		$4.20 /yd3	$924,000	$462,000
Revegetation		$0.12 /yd3	$26,400	$13,200
Monitoring Wells		$2,000 /well	$12,000	$12,000
Subtotal			$8,548,300	$4,354,400
Contingency (20%)			$1,709,660	$870,880
Mobilization, Bonding, Insurance (10%)			$854,830	$435,440
Subtotal			$11,112,790	$5,660,720
Administration, Engineering (15%)			$1,666,919	$849,108
Total Initial Costs			$12,780,000	$6,510,000
O&M UNIT COSTS				
Site maintenance (30 yr)		$0.16 /yd3	$331,936	$165,968
Monitoring we	6 wells/site		6	6
Chemical anal	1 sample/well	$1,200 /sample	$27,288	$27,288
		$1,200 /sample		
Annual sampling for 5 yr				
Contingency (20%)			$71,845	$38,651
Present Worth of O&M Costs (10% Discount, 30 yr maintenance, 5 yr monitoring)			$431,000	$232,000
COST SUMMARY				
Total Alternative Costs			$13,211,000	$6,742,000

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TABLE D-13 Hydraulic Dredge/Solidification/Upland Disposal Alternative

			Example	
		Depth (yd)	1	2
		Area (yd2)	370000	220000
		Volume (yd3)	370000	440000
INITIAL COSTS		Unit Costs ($)	Cost ($)	Costs ($)
Site Acquisition (15 ft fill)		$25,000 /acre	$382,231	$454,545
Site Preparation (10% Site Acquisition)			$38,223	$45,455
Sampling Program				
Sediment Core (one per 4,000 yd3)		$1,500 /core	$139,500	$139,500
Chemical Analysis (one per core)		waterway dependent	$111,600	$111,600
Hydraulic Dredge/Solidification/Upland Disposal				
Dike and Berm Construction		$0.40 /yd3	$148,000	$176,000
Clarification Unit Construction		$0.10 /yd3	$37,000	$44,000
Cutterhead (3 mile transport)		$1.50 /yd3	$555,000	$660,000
Pipeline Boosters (2 units)		$1.00 /yd3	$370,000	$440,000
Liner (3 ft clay)		$4.20 /yd3	$1,554,000	$1,848,000
Underdrain		$0.12 /yd3	$44,400	$52,800
Chemical Clarification		$0.35 /yd3	$129,500	$154,000
Solidification		$25.00 /yd3	$9,250,000	$11,000,000
Cover (3 ft clay or soil)		$4.20 /yd3	$1,554,000	$1,848,000
Revegetation		$0.12 /yd3	$44,400	$52,800
Monitoring Wells		$2,000 /well	$12,000	$12,000
Subtotal			$14,369,855	$17,038,700
Contingency (20%)			$2,873,971	$3,407,740
Mobilization, Bonding, Insurance (10%)			$1,436,985	$1,703,870
Subtotal			$18,680,811	$22,150,310
Administration, Engineering (15%)			$2,802,122	$3,322,547
Total Initial Costs			$21,483,000	$25,473,000
O&M UNIT COSTS				
Site maintenance (30 yr)		$0.16 /yd3	$558,256	$663,872
Monitoring we	6 wells/site		6	6
Chemical anal	1 sample/well	$1,200 /sample	$27,288	$27,288
		$1,200 /sample		
Annual sampling for 5 yr				
Contingency (20%)			$117,109	$138,232
Present Worth of O&M Costs (10% Discount, 30 yr maintenance, 5 yr monitoring)			$703,000	$829,000
COST SUMMARY				
Total Alternative Costs			$22,186,000	$26,302,000

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TABLE D- . Unit Costs for Remedial Activities.

	Unit costs ($)
INITIAL COSTS	
Sampling Program	
Sediment Core (one per 4,000 yd3 of cleanup volume)	$1,500 /core
Chemical Analysis (one per core)	waterway dependent
Dredging Operations	
Cutterhead Dredge	$1.50 /yd3
Pipeline Booster	$0.50 /yd3
Clamshell Bucket Modification	$20,000
Clamshell Dredge	$1.25 /yd3
Barge Transport (up to 5 miles)	$0.50 /yd3
Truck Transport (2 miles round trip, 2 loads/hr)	$2.01 /yd3
Treatment	
Solidification	$22.00 /yd3
Solvent Extraction	$120.00 /yd3
Thermal Treatment	$300.00 /yd3
Chemical Clarification	$0.35 /yd3
Land Treatment Treatability Study	$100,000
Disposal	
Site Acquisition (Nearshore)	$43,000 /acre
Site Acquisition (Upland)	$25,000 /acre
Site Preparation	10% of Site Acquisition
Dike and Berm (Nearshore)	$0.70 /yd3
Dike and Berm (Upland)	$0.40 /yd3
Clarification Unit (Nearshore)	$0.18 /yd3
Clarification Unit (Upland)	$0.10 /yd3
Clay Cap (3 ft over 15 ft fill, Upland)	$4.20 /yd3
Clay Cap (3 ft over 30 ft fill, Nearshore)	$2.10 /yd3
Clay Liner (3 ft)	$4.20 /yd3
Clay Liner (1 ft)	$1.40 /yd3
Synthetic Liner (30 mil Butyl/EPDM)	$1.00 /yd3
Drainage Sand/Gravel (1 ft)	$0.80 /yd3
Underdrain (Leachate Collection)	$0.12 /yd3
Run-on and Run-off Controls (Land Treatment)	$0.20 /yd3
Topsoil Vegetative Layer (2 ft)	$0.60 /yd3
Revegetation	$0.12 /yd3
Underwater Diffuser (for Open-water CAD)	$1.20 /yd3
Intertidal Mitigation	
Clamshell Dredge of Capping Materials	$1.25 /yd3
Barge Transport (up to 5 miles)	$0.50 /yd3
Institutional Control and Monitoring	

TABLE D-1 - Unit Costs for Remedial Activities.

	Unit costs ($)
Sediment Core Samples	$1,500 /core
Monitoring Wells	$2,000 /well
Signs for Access Restriction	$25,000 /waterway
Contingency	20% of Initial Cost
Mobilization, Bonding, and Insurance	10% of Initial Cost and Contingency Cost
Administration and Engineering	15% of Initial Costs, Contingency, and Mobilization Cost
OPERATIONAL AND MAINTENANCE (O&M) COSTS	
Educational Programs for Institutional Control	$15,000 /waterway/yr
Site Inspection and Maintenance for	
In-situ capping	$0.10 /yd2/yr
Confined aquatic disposal	$0.08 /yd3/yr
Nearshore disposal	$0.08 /yd3/yr
Upland disposal	$0.16 /yd3/yr
Land treatment	$0.32 /yd3/yr
Monitoring Program (5 to 30 years)	
Monitoring Stations and Wells	
1 station/acre, 30 stations maximum per waterway	
1 well/25,000 yd3, minimum 6 and maximum 15 wells per disposal site w/o treatment; 6 wells per disposal site w/ treatment	
Lysimeters (20 per site for land treatment)a	$250 /each
Chemical Sampling and Analyses	
3 samples/station or 1 sample/well	$1,200 /sample
Contingency	20% of O&M Cost
Present Worth of Total O&M Cost Calculated on 10% Discount Rate, 5 to 30 years	

TOTAL ALTERNATIVE COST = Total Initial Cost + Present Worth of Total O&M Cost